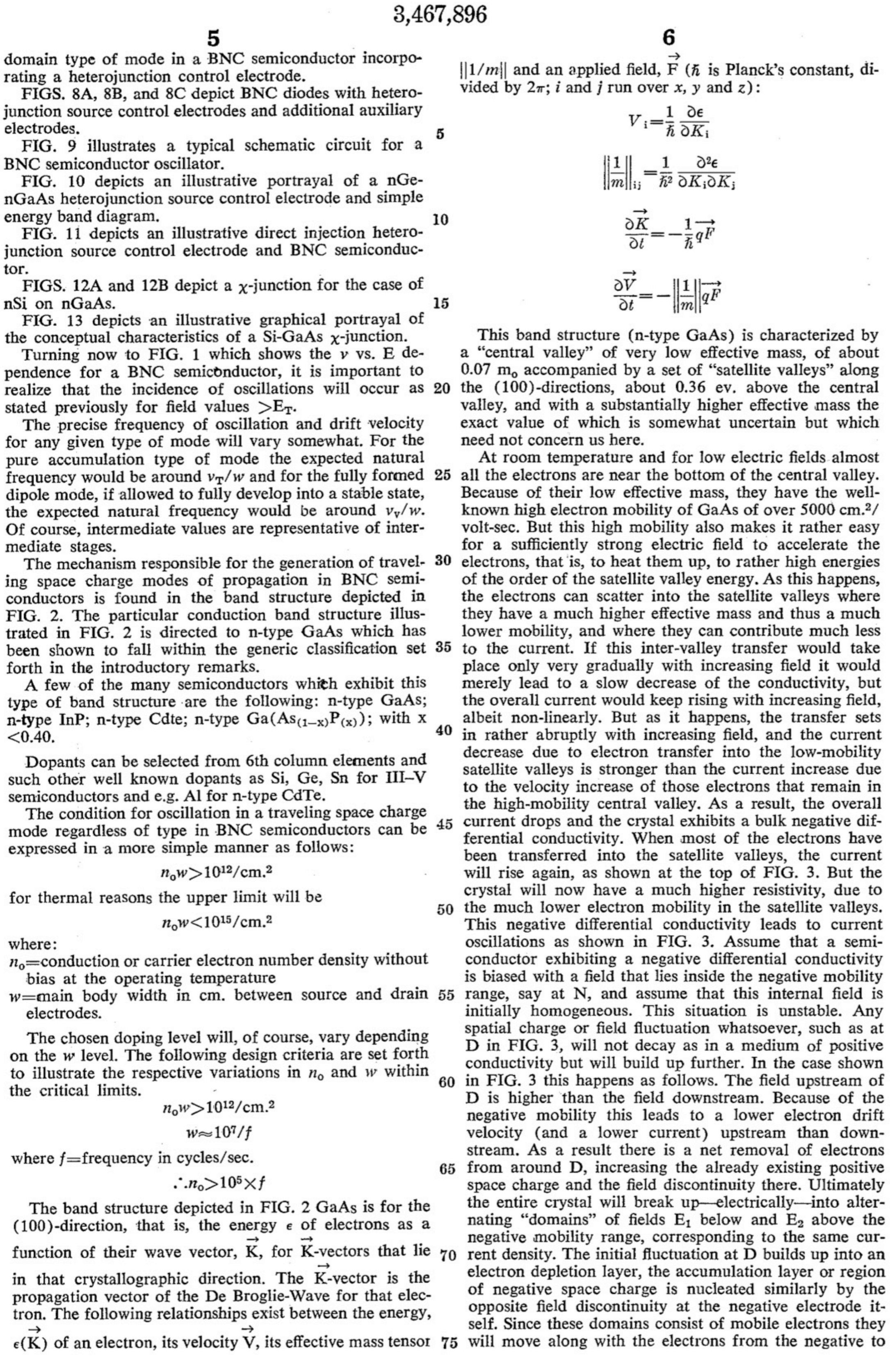

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domain type of mode in a BNC semiconductor incorporating a heterojunction control electrode.

FIGS. 8A, 8B, and 8C depict BNC diodes with heterojunction source control electrodes and additional auxiliary electrodes.

FIG. 9 illustrates a typical schematic circuit for a BNC semiconductor oscillator.

FIG. 10 depicts an illustrative portrayal of a nGe-nGaAs heterojunction source control electrode and simple energy band diagram.

FIG. 11 depicts an illustrative direct injection heterojunction source control electrode and BNC semiconductor.

FIGS. 12A and 12B depict a χ-junction for the case of nSi on nGaAs.

FIG. 13 depicts an illustrative graphical portrayal of the conceptual characteristics of a Si-GaAs χ-junction.

Turning now to FIG. 1 which shows the v vs. E dependence for a BNC semiconductor, it is important to realize that the incidence of oscillations will occur as stated previously for field values $>E_T$.

The precise frequency of oscillation and drift velocity for any given type of mode will vary somewhat. For the pure accumulation type of mode the expected natural frequency would be around v_T/w and for the fully formed dipole mode, if allowed to fully develop into a stable state, the expected natural frequency would be around v_v/w. Of course, intermediate values are representative of intermediate stages.

The mechanism responsible for the generation of traveling space charge modes of propagation in BNC semiconductors is found in the band structure depicted in FIG. 2. The particular conduction band structure illustrated in FIG. 2 is directed to n-type GaAs which has been shown to fall within the generic classification set forth in the introductory remarks.

A few of the many semiconductors which exhibit this type of band structure are the following: n-type GaAs; n-type InP; n-type Cdte; n-type $Ga(As_{(1-x)}P_{(x)})$; with x <0.40.

Dopants can be selected from 6th column elements and such other well known dopants as Si, Ge, Sn for III–V semiconductors and e.g. Al for n-type CdTe.

The condition for oscillation in a traveling space charge mode regardless of type in BNC semiconductors can be expressed in a more simple manner as follows:

$$n_ow>10^{12}/\text{cm.}^2$$

for thermal reasons the upper limit will be

$$n_ow<10^{15}/\text{cm.}^2$$

where:

n_o=conduction or carrier electron number density without bias at the operating temperature

w=main body width in cm. between source and drain electrodes.

The chosen doping level will, of course, vary depending on the w level. The following design criteria are set forth to illustrate the respective variations in n_o and w within the critical limits.

$$n_ow>10^{12}/\text{cm.}^2$$

$$w\approx 10^7/f$$

where f=frequency in cycles/sec.

$$\therefore n_o>10^5\times f$$

The band structure depicted in FIG. 2 GaAs is for the (100)-direction, that is, the energy ϵ of electrons as a function of their wave vector, $\vec{K}$, for $\vec{K}$-vectors that lie in that crystallographic direction. The $\vec{K}$-vector is the propagation vector of the De Broglie-Wave for that electron. The following relationships exist between the energy, $\epsilon(\vec{K})$ of an electron, its velocity $\vec{V}$, its effective mass tensor

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$\|1/m\|$ and an applied field, $\vec{F}$ ($\hbar$ is Planck's constant, divided by 2π; i and j run over x, y and z):

$$V_i=\frac{1}{\hbar}\frac{\partial\epsilon}{\partial K_i}$$

$$\left\|\frac{1}{m}\right\|_{ij}=\frac{1}{\hbar^2}\frac{\partial^2\epsilon}{\partial K_i\partial K_j}$$

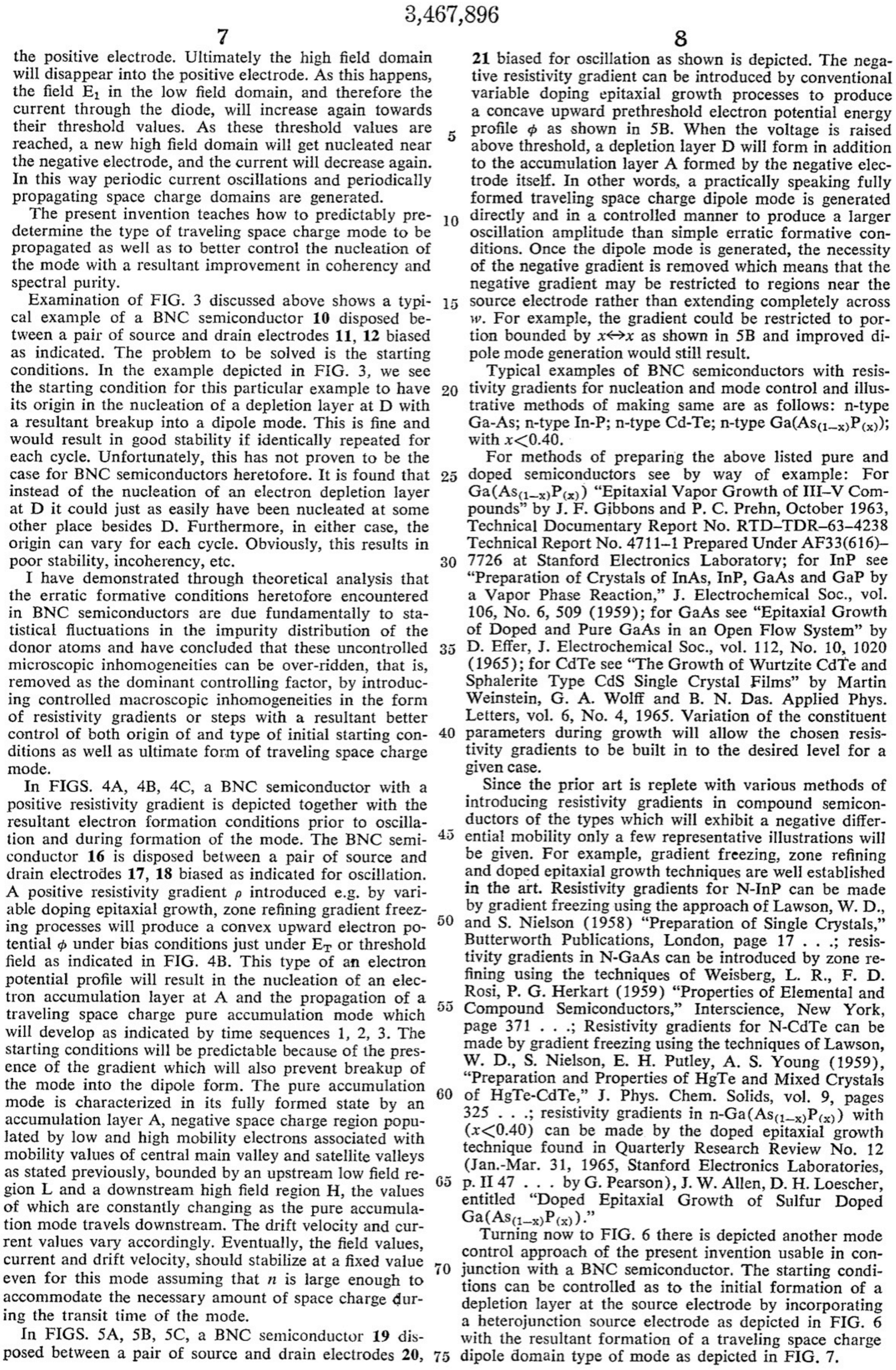
$$\frac{\partial\vec{K}}{\partial t}=-\frac{1}{\hbar}\overrightarrow{qF}$$

$$\frac{\partial\vec{V}}{\partial t}=-\left\|\frac{1}{m}\right\|\overrightarrow{qF}$$

This band structure (n-type GaAs) is characterized by a "central valley" of very low effective mass, of about 0.07 m_o accompanied by a set of "satellite valleys" along the (100)-directions, about 0.36 ev. above the central valley, and with a substantially higher effective mass the exact value of which is somewhat uncertain but which need not concern us here.

At room temperature and for low electric fields almost all the electrons are near the bottom of the central valley. Because of their low effective mass, they have the well-known high electron mobility of GaAs of over 5000 cm.^{2}/volt-sec. But this high mobility also makes it rather easy for a sufficiently strong electric field to accelerate the electrons, that is, to heat them up, to rather high energies of the order of the satellite valley energy. As this happens, the electrons can scatter into the satellite valleys where they have a much higher effective mass and thus a much lower mobility, and where they can contribute much less to the current. If this inter-valley transfer would take place only very gradually with increasing field it would merely lead to a slow decrease of the conductivity, but the overall current would keep rising with increasing field, albeit non-linearly. But as it happens, the transfer sets in rather abruptly with increasing field, and the current decrease due to electron transfer into the low-mobility satellite valleys is stronger than the current increase due to the velocity increase of those electrons that remain in the high-mobility central valley. As a result, the overall current drops and the crystal exhibits a bulk negative differential conductivity. When most of the electrons have been transferred into the satellite valleys, the current will rise again, as shown at the top of FIG. 3. But the crystal will now have a much higher resistivity, due to the much lower electron mobility in the satellite valleys. This negative differential conductivity leads to current oscillations as shown in FIG. 3. Assume that a semiconductor exhibiting a negative differential conductivity is biased with a field that lies inside the negative mobility range, say at N, and assume that this internal field is initially homogeneous. This situation is unstable. Any spatial charge or field fluctuation whatsoever, such as at D in FIG. 3, will not decay as in a medium of positive conductivity but will build up further. In the case shown in FIG. 3 this happens as follows. The field upstream of D is higher than the field downstream. Because of the negative mobility this leads to a lower electron drift velocity (and a lower current) upstream than downstream. As a result there is a net removal of electrons from around D, increasing the already existing positive space charge and the field discontinuity there. Ultimately the entire crystal will break up—electrically—into alternating "domains" of fields E_1 below and E_2 above the negative mobility range, corresponding to the same current density. The initial fluctuation at D builds up into an electron depletion layer, the accumulation layer or region of negative space charge is nucleated similarly by the opposite field discontinuity at the negative electrode itself. Since these domains consist of mobile electrons they will move along with the electrons from the negative to

Figure B.162: Herbert Kroemer invented III-V semiconductor heterostructures in 1966.



the positive electrode. Ultimately the high field domain will disappear into the positive electrode. As this happens, the field E_1 in the low field domain, and therefore the current through the diode, will increase again towards their threshold values. As these threshold values are reached, a new high field domain will get nucleated near the negative electrode, and the current will decrease again. In this way periodic current oscillations and periodically propagating space charge domains are generated.

The present invention teaches how to predictably predetermine the type of traveling space charge mode to be propagated as well as to better control the nucleation of the mode with a resultant improvement in coherency and spectral purity.

Examination of FIG. 3 discussed above shows a typical example of a BNC semiconductor **10** disposed between a pair of source and drain electrodes **11**, **12** biased as indicated. The problem to be solved is the starting conditions. In the example depicted in FIG. 3, we see the starting condition for this particular example to have its origin in the nucleation of a depletion layer at D with a resultant breakup into a dipole mode. This is fine and would result in good stability if identically repeated for each cycle. Unfortunately, this has not proven to be the case for BNC semiconductors heretofore. It is found that instead of the nucleation of an electron depletion layer at D it could just as easily have been nucleated at some other place besides D. Furthermore, in either case, the origin can vary for each cycle. Obviously, this results in poor stability, incoherency, etc.

I have demonstrated through theoretical analysis that the erratic formative conditions heretofore encountered in BNC semiconductors are due fundamentally to statistical fluctuations in the impurity distribution of the donor atoms and have concluded that these uncontrolled microscopic inhomogeneities can be over-ridden, that is, removed as the dominant controlling factor, by introducing controlled macroscopic inhomogeneities in the form of resistivity gradients or steps with a resultant better control of both origin of and type of initial starting conditions as well as ultimate form of traveling space charge mode.

In FIGS. 4A, 4B, 4C, a BNC semiconductor with a positive resistivity gradient is depicted together with the resultant electron formation conditions prior to oscillation and during formation of the mode. The BNC semiconductor **16** is disposed between a pair of source and drain electrodes **17**, **18** biased as indicated for oscillation. A positive resistivity gradient ρ introduced e.g. by variable doping epitaxial growth, zone refining gradient freezing processes will produce a convex upward electron potential ϕ under bias conditions just under E_T or threshold field as indicated in FIG. 4B. This type of an electron potential profile will result in the nucleation of an electron accumulation layer at A and the propagation of a traveling space charge pure accumulation mode which will develop as indicated by time sequences 1, 2, 3. The starting conditions will be predictable because of the presence of the gradient which will also prevent breakup of the mode into the dipole form. The pure accumulation mode is characterized in its fully formed state by an accumulation layer A, negative space charge region populated by low and high mobility electrons associated with mobility values of central main valley and satellite valleys as stated previously, bounded by an upstream low field region L and a downstream high field region H, the values of which are constantly changing as the pure accumulation mode travels downstream. The drift velocity and current values vary accordingly. Eventually, the field values, current and drift velocity, should stabilize at a fixed value even for this mode assuming that n is large enough to accommodate the necessary amount of space charge during the transit time of the mode.

In FIGS. 5A, 5B, 5C, a BNC semiconductor **19** disposed between a pair of source and drain electrodes **20**, **21** biased for oscillation as shown is depicted. The negative resistivity gradient can be introduced by conventional variable doping epitaxial growth processes to produce a concave upward prethreshold electron potential energy profile ϕ as shown in 5B. When the voltage is raised above threshold, a depletion layer D will form in addition to the accumulation layer A formed by the negative electrode itself. In other words, a practically speaking fully formed traveling space charge dipole mode is generated directly and in a controlled manner to produce a larger oscillation amplitude than simple erratic formative conditions. Once the dipole mode is generated, the necessity of the negative gradient is removed which means that the negative gradient may be restricted to regions near the source electrode rather than extending completely across w. For example, the gradient could be restricted to portion bounded by $x \leftrightarrow x$ as shown in 5B and improved dipole mode generation would still result.

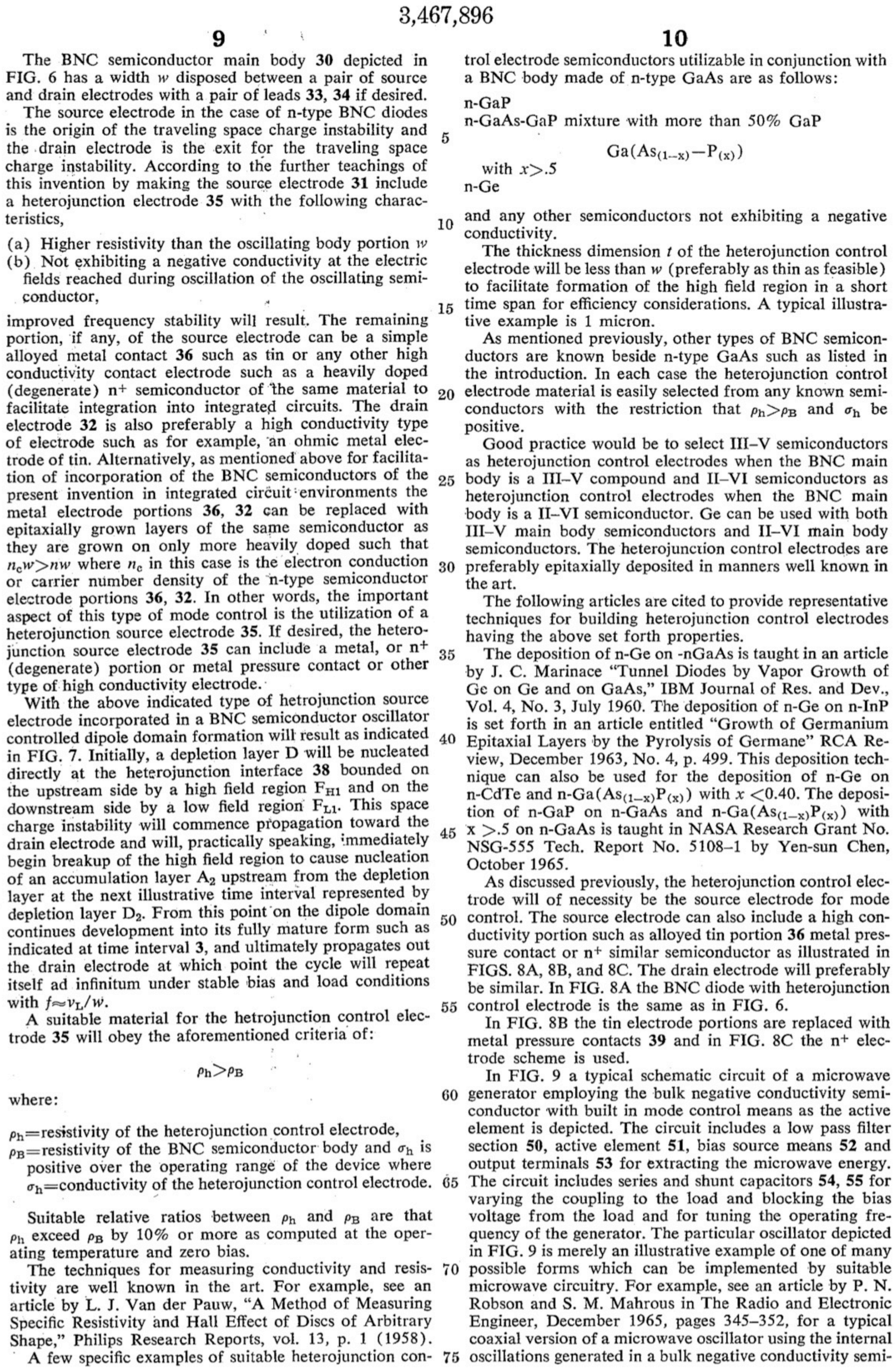
Typical examples of BNC semiconductors with resistivity gradients for nucleation and mode control and illustrative methods of making same are as follows: n-type Ga-As; n-type In-P; n-type Cd-Te; n-type Ga(As$_{(1-x)}$P$_{(x)}$); with $x<0.40$.

For methods of preparing the above listed pure and doped semiconductors see by way of example: For Ga(As$_{(1-x)}$P$_{(x)}$) "Epitaxial Vapor Growth of III–V Compounds" by J. F. Gibbons and P. C. Prehn, October 1963, Technical Documentary Report No. RTD–TDR–63–4238 Technical Report No. 4711–1 Prepared Under AF33(616)–7726 at Stanford Electronics Laboratory; for InP see "Preparation of Crystals of InAs, InP, GaAs and GaP by a Vapor Phase Reaction," J. Electrochemical Soc., vol. 106, No. 6, 509 (1959); for GaAs see "Epitaxial Growth of Doped and Pure GaAs in an Open Flow System" by D. Effer, J. Electrochemical Soc., vol. 112, No. 10, 1020 (1965); for CdTe see "The Growth of Wurtzite CdTe and Sphalerite Type CdS Single Crystal Films" by Martin Weinstein, G. A. Wolff and B. N. Das. Applied Phys. Letters, vol. 6, No. 4, 1965. Variation of the constituent parameters during growth will allow the chosen resistivity gradients to be built in to the desired level for a given case.

Since the prior art is replete with various methods of introducing resistivity gradients in compound semiconductors of the types which will exhibit a negative differential mobility only a few representative illustrations will be given. For example, gradient freezing, zone refining and doped epitaxial growth techniques are well established in the art. Resistivity gradients for N-InP can be made by gradient freezing using the approach of Lawson, W. D., and S. Nielson (1958) "Preparation of Single Crystals," Butterworth Publications, London, page 17 . . .; resistivity gradients in N-GaAs can be introduced by zone refining using the techniques of Weisberg, L. R., F. D. Rosi, P. G. Herkart (1959) "Properties of Elemental and Compound Semiconductors," Interscience, New York, page 371 . . .; Resistivity gradients for N-CdTe can be made by gradient freezing using the techniques of Lawson, W. D., S. Nielson, E. H. Putley, A. S. Young (1959), "Preparation and Properties of HgTe and Mixed Crystals of HgTe-CdTe," J. Phys. Chem. Solids, vol. 9, pages 325 . . .; resistivity gradients in n-Ga(As$_{(1-x)}$P$_{(x)}$) with ($x<0.40$) can be made by the doped epitaxial growth technique found in Quarterly Research Review No. 12 (Jan.-Mar. 31, 1965, Stanford Electronics Laboratories, p. II 47 . . . by G. Pearson), J. W. Allen, D. H. Loescher, entitled "Doped Epitaxial Growth of Sulfur Doped Ga(As$_{(1-x)}$P$_{(x)}$)."

Turning now to FIG. 6 there is depicted another mode control approach of the present invention usable in conjunction with a BNC semiconductor. The starting conditions can be controlled as to the initial formation of a depletion layer at the source electrode by incorporating a heterojunction source electrode as depicted in FIG. 6 with the resultant formation of a traveling space charge dipole domain type of mode as depicted in FIG. 7.

Figure B.163: Herbert Kroemer invented III-V semiconductor heterostructures in 1966.



The BNC semiconductor main body **30** depicted in FIG. 6 has a width w disposed between a pair of source and drain electrodes with a pair of leads **33, 34** if desired.

The source electrode in the case of n-type BNC diodes is the origin of the traveling space charge instability and the drain electrode is the exit for the traveling space charge instability. According to the further teachings of this invention by making the source electrode **31** include a heterojunction electrode **35** with the following characteristics,

(a) Higher resistivity than the oscillating body portion w
(b) Not exhibiting a negative conductivity at the electric fields reached during oscillation of the oscillating semiconductor,

improved frequency stability will result. The remaining portion, if any, of the source electrode can be a simple alloyed metal contact **36** such as tin or any other high conductivity contact electrode such as a heavily doped (degenerate) n^+ semiconductor of the same material to facilitate integration into integrated circuits. The drain electrode **32** is also preferably a high conductivity type of electrode such as for example, an ohmic metal electrode of tin. Alternatively, as mentioned above for facilitation of incorporation of the BNC semiconductors of the present invention in integrated circuit environments the metal electrode portions **36, 32** can be replaced with epitaxially grown layers of the same semiconductor as they are grown on only more heavily doped such that $n_c w > nw$ where n_c in this case is the electron conduction or carrier number density of the n-type semiconductor electrode portions **36, 32**. In other words, the important aspect of this type of mode control is the utilization of a heterojunction source electrode **35**. If desired, the heterojunction source electrode **35** can include a metal, or n^+ (degenerate) portion or metal pressure contact or other type of high conductivity electrode.

With the above indicated type of hetrojunction source electrode incorporated in a BNC semiconductor oscillator controlled dipole domain formation will result as indicated in FIG. 7. Initially, a depletion layer D will be nucleated directly at the heterojunction interface **38** bounded on the upstream side by a high field region F_{H1} and on the downstream side by a low field region F_{L1}. This space charge instability will commence propagation toward the drain electrode and will, practically speaking, immediately begin breakup of the high field region to cause nucleation of an accumulation layer A_2 upstream from the depletion layer at the next illustrative time interval represented by depletion layer D_2. From this point on the dipole domain continues development into its fully mature form such as indicated at time interval **3**, and ultimately propagates out the drain electrode at which point the cycle will repeat itself ad infinitum under stable bias and load conditions with $f \approx v_L/w$.

A suitable material for the hetrojunction control electrode **35** will obey the aforementioned criteria of:

$$\rho_h > \rho_B$$

where:

ρ_h=resistivity of the heterojunction control electrode,
ρ_B=resistivity of the BNC semiconductor body and σ_h is positive over the operating range of the device where σ_h=conductivity of the heterojunction control electrode.

Suitable relative ratios between ρ_h and ρ_B are that ρ_h exceed ρ_B by 10% or more as computed at the operating temperature and zero bias.

The techniques for measuring conductivity and resistivity are well known in the art. For example, see an article by L. J. Van der Pauw, "A Method of Measuring Specific Resistivity and Hall Effect of Discs of Arbitrary Shape," Philips Research Reports, vol. 13, p. 1 (1958).

A few specific examples of suitable heterojunction control electrode semiconductors utilizable in conjunction with a BNC body made of n-type GaAs are as follows:

n-GaP
n-GaAs-GaP mixture with more than 50% GaP

$$\mathrm{Ga}(\mathrm{As}_{(1-x)}-\mathrm{P}_{(x)})$$

with $x > .5$
n-Ge

and any other semiconductors not exhibiting a negative conductivity.

The thickness dimension t of the heterojunction control electrode will be less than w (preferably as thin as feasible) to facilitate formation of the high field region in a short time span for efficiency considerations. A typical illustrative example is 1 micron.

As mentioned previously, other types of BNC semiconductors are known beside n-type GaAs such as listed in the introduction. In each case the heterojunction control electrode material is easily selected from any known semiconductors with the restriction that $\rho_h > \rho_B$ and σ_h be positive.

Good practice would be to select III–V semiconductors as heterojunction control electrodes when the BNC main body is a III–V compound and II–VI semiconductors as heterojunction control electrodes when the BNC main body is a II–VI semiconductor. Ge can be used with both III–V main body semiconductors and II–VI main body semiconductors. The heterojunction control electrodes are preferably epitaxially deposited in manners well known in the art.

The following articles are cited to provide representative techniques for building heterojunction control electrodes having the above set forth properties.

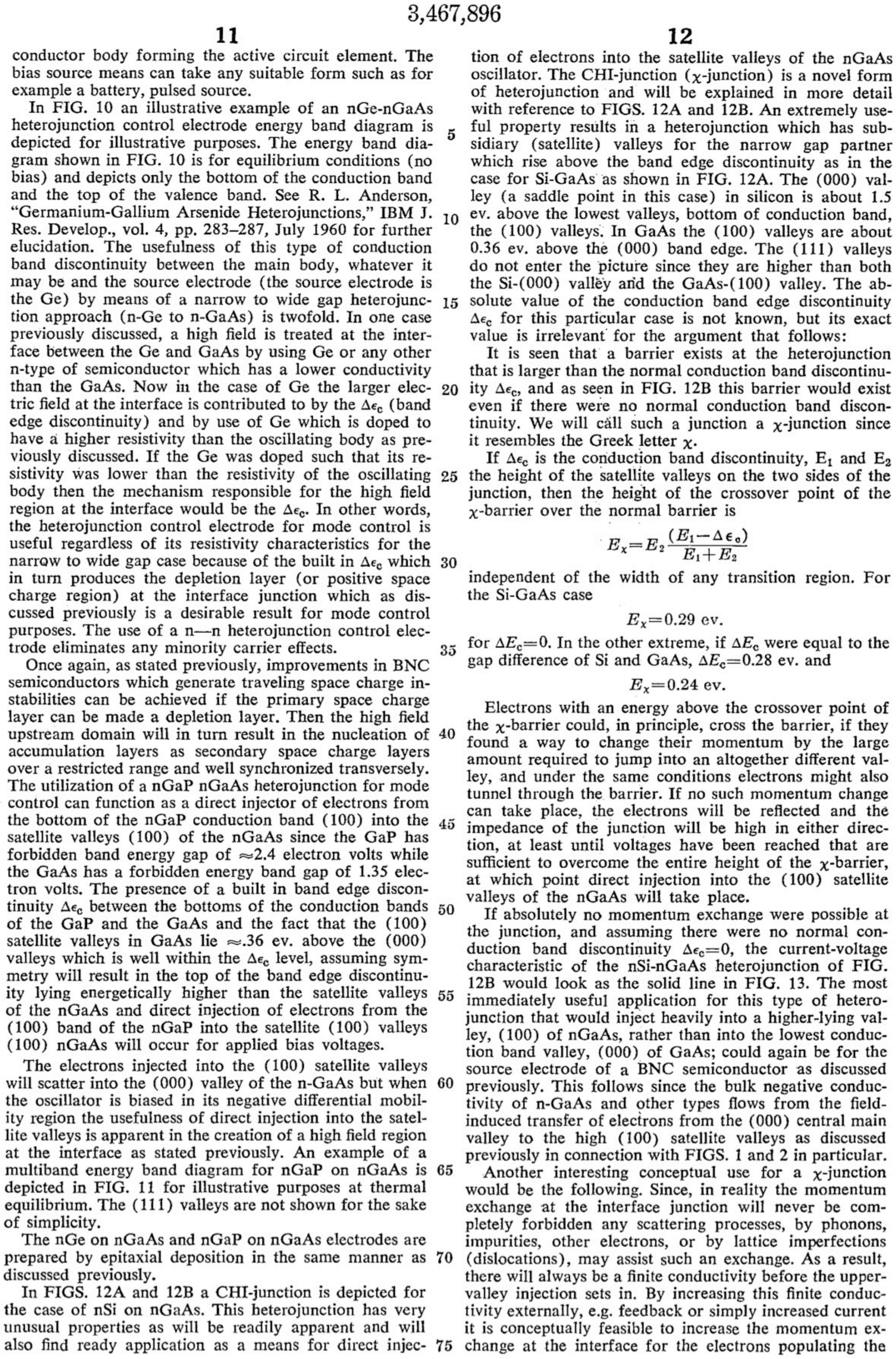
The deposition of n-Ge on -nGaAs is taught in an article by J. C. Marinace "Tunnel Diodes by Vapor Growth of Ge on Ge and on GaAs," IBM Journal of Res. and Dev., Vol. 4, No. 3, July 1960. The deposition of n-Ge on n-InP is set forth in an article entitled "Growth of Germanium Epitaxial Layers by the Pyrolysis of Germane" RCA Review, December 1963, No. 4, p. 499. This deposition technique can also be used for the deposition of n-Ge on n-CdTe and n-$\mathrm{Ga}(\mathrm{As}_{(1-x)}\mathrm{P}_{(x)})$ with $x < 0.40$. The deposition of n-GaP on n-GaAs and n-$\mathrm{Ga}(\mathrm{As}_{(1-x)}\mathrm{P}_{(x)})$ with $x > .5$ on n-GaAs is taught in NASA Research Grant No. NSG-555 Tech. Report No. 5108–1 by Yen-sun Chen, October 1965.

As discussed previously, the heterojunction control electrode will of necessity be the source electrode for mode control. The source electrode can also include a high conductivity portion such as alloyed tin portion **36** metal pressure contact or n^+ similar semiconductor as illustrated in FIGS. 8A, 8B, and 8C. The drain electrode will preferably be similar. In FIG. 8A the BNC diode with heterojunction control electrode is the same as in FIG. 6.

In FIG. 8B the tin electrode portions are replaced with metal pressure contacts **39** and in FIG. 8C the n^+ electrode scheme is used.

In FIG. 9 a typical schematic circuit of a microwave generator employing the bulk negative conductivity semiconductor with built in mode control means as the active element is depicted. The circuit includes a low pass filter section **50**, active element **51**, bias source means **52** and output terminals **53** for extracting the microwave energy. The circuit includes series and shunt capacitors **54, 55** for varying the coupling to the load and blocking the bias voltage from the load and for tuning the operating frequency of the generator. The particular oscillator depicted in FIG. 9 is merely an illustrative example of one of many possible forms which can be implemented by suitable microwave circuitry. For example, see an article by P. N. Robson and S. M. Mahrous in The Radio and Electronic Engineer, December 1965, pages 345–352, for a typical coaxial version of a microwave oscillator using the internal oscillations generated in a bulk negative conductivity semi-

Figure B.164: Herbert Kroemer invented III-V semiconductor heterostructures in 1966.



conductor body forming the active circuit element. The bias source means can take any suitable form such as for example a battery, pulsed source.

In FIG. 10 an illustrative example of an nGe-nGaAs heterojunction control electrode energy band diagram is depicted for illustrative purposes. The energy band diagram shown in FIG. 10 is for equilibrium conditions (no bias) and depicts only the bottom of the conduction band and the top of the valence band. See R. L. Anderson, "Germanium-Gallium Arsenide Heterojunctions," IBM J. Res. Develop., vol. 4, pp. 283–287, July 1960 for further elucidation. The usefulness of this type of conduction band discontinuity between the main body, whatever it may be and the source electrode (the source electrode is the Ge) by means of a narrow to wide gap heterojunction approach (n-Ge to n-GaAs) is twofold. In one case previously discussed, a high field is treated at the interface between the Ge and GaAs by using Ge or any other n-type of semiconductor which has a lower conductivity than the GaAs. Now in the case of Ge the larger electric field at the interface is contributed to by the $\Delta\epsilon_c$ (band edge discontinuity) and by use of Ge which is doped to have a higher resistivity than the oscillating body as previously discussed. If the Ge was doped such that its resistivity was lower than the resistivity of the oscillating body then the mechanism responsible for the high field region at the interface would be the $\Delta\epsilon_c$. In other words, the heterojunction control electrode for mode control is useful regardless of its resistivity characteristics for the narrow to wide gap case because of the built in $\Delta\epsilon_c$ which in turn produces the depletion layer (or positive space charge region) at the interface junction which as discussed previously is a desirable result for mode control purposes. The use of a n—n heterojunction control electrode eliminates any minority carrier effects.

Once again, as stated previously, improvements in BNC semiconductors which generate traveling space charge instabilities can be achieved if the primary space charge layer can be made a depletion layer. Then the high field upstream domain will in turn result in the nucleation of accumulation layers as secondary space charge layers over a restricted range and well synchronized transversely. The utilization of a nGaP nGaAs heterojunction for mode control can function as a direct injector of electrons from the bottom of the nGaP conduction band (100) into the satellite valleys (100) of the nGaAs since the GaP has forbidden band energy gap of $\approx$2.4 electron volts while the GaAs has a forbidden energy band gap of 1.35 electron volts. The presence of a built in band edge discontinuity $\Delta\epsilon_c$ between the bottoms of the conduction bands of the GaP and the GaAs and the fact that the (100) satellite valleys in GaAs lie $\approx$.36 ev. above the (000) valleys which is well within the $\Delta\epsilon_c$ level, assuming symmetry will result in the top of the band edge discontinuity lying energetically higher than the satellite valleys of the nGaAs and direct injection of electrons from the (100) band of the nGaP into the satellite (100) valleys (100) nGaAs will occur for applied bias voltages.

The electrons injected into the (100) satellite valleys will scatter into the (000) valley of the n-GaAs but when the oscillator is biased in its negative differential mobility region the usefulness of direct injection into the satellite valleys is apparent in the creation of a high field region at the interface as stated previously. An example of a multiband energy band diagram for nGaP on nGaAs is depicted in FIG. 11 for illustrative purposes at thermal equilibrium. The (111) valleys are not shown for the sake of simplicity.

The nGe on nGaAs and nGaP on nGaAs electrodes are prepared by epitaxial deposition in the same manner as discussed previously.

In FIGS. 12A and 12B a CHI-junction is depicted for the case of nSi on nGaAs. This heterojunction has very unusual properties as will be readily apparent and will also find ready application as a means for direct injection of electrons into the satellite valleys of the nGaAs oscillator. The CHI-junction (χ-junction) is a novel form of heterojunction and will be explained in more detail with reference to FIGS. 12A and 12B. An extremely useful property results in a heterojunction which has subsidiary (satellite) valleys for the narrow gap partner which rise above the band edge discontinuity as in the case for Si-GaAs as shown in FIG. 12A. The (000) valley (a saddle point in this case) in silicon is about 1.5 ev. above the lowest valleys, bottom of conduction band, the (100) valleys. In GaAs the (100) valleys are about 0.36 ev. above the (000) band edge. The (111) valleys do not enter the picture since they are higher than both the Si-(000) valley and the GaAs-(100) valley. The absolute value of the conduction band edge discontinuity $\Delta\epsilon_c$ for this particular case is not known, but its exact value is irrelevant for the argument that follows:

It is seen that a barrier exists at the heterojunction that is larger than the normal conduction band discontinuity $\Delta\epsilon_c$, and as seen in FIG. 12B this barrier would exist even if there were no normal conduction band discontinuity. We will call such a junction a χ-junction since it resembles the Greek letter χ.

If $\Delta\epsilon_c$ is the conduction band discontinuity, E_1 and E_2 the height of the satellite valleys on the two sides of the junction, then the height of the crossover point of the χ-barrier over the normal barrier is

$$E_x = E_2 \frac{(E_1 - \Delta\epsilon_c)}{E_1 + E_2}$$

independent of the width of any transition region. For the Si-GaAs case

$$E_x = 0.29 \text{ ev.}$$

for $\Delta E_c = 0$. In the other extreme, if ΔE_c were equal to the gap difference of Si and GaAs, $\Delta E_c = 0.28$ ev. and

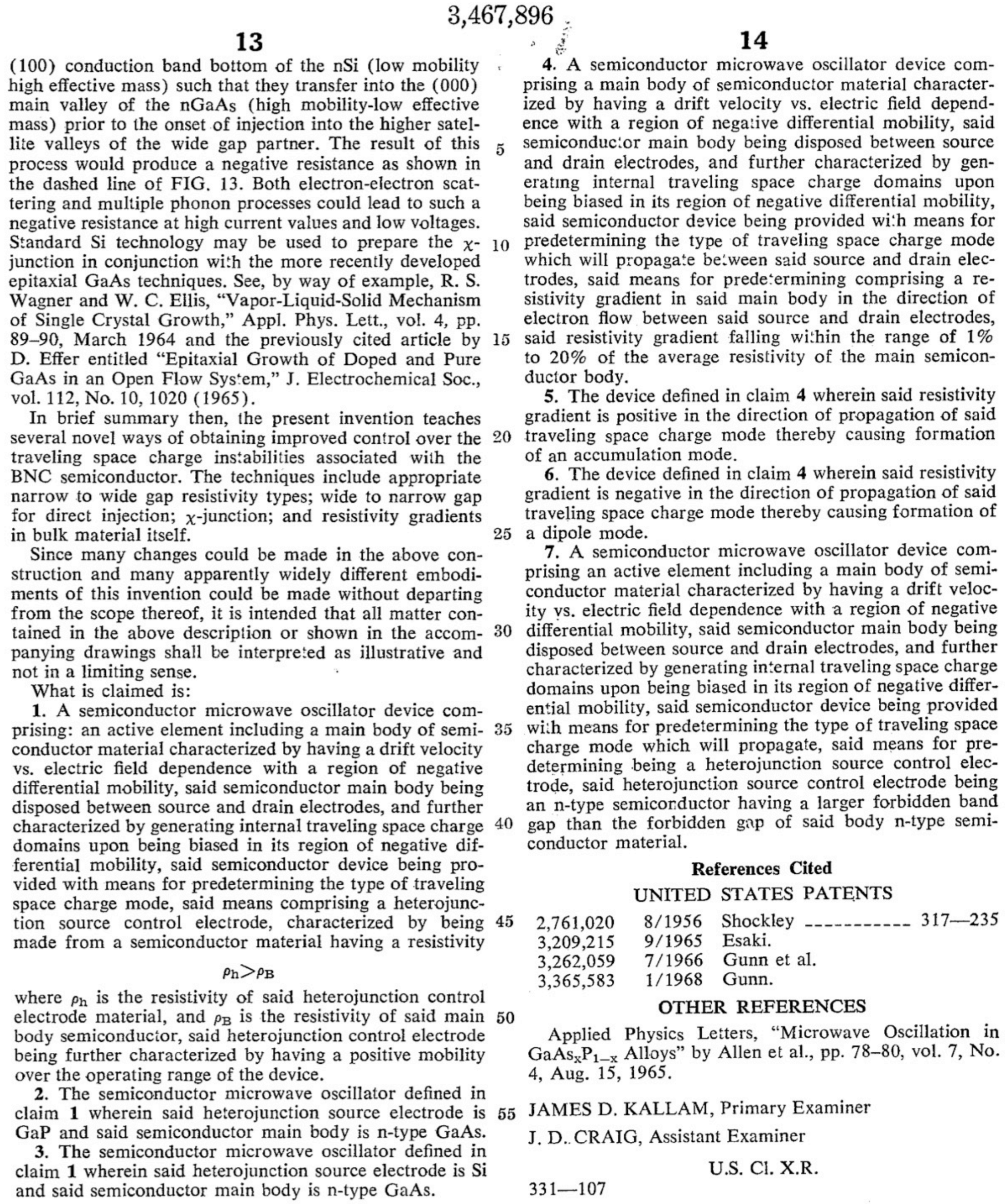
$$E_x = 0.24 \text{ ev.}$$

Electrons with an energy above the crossover point of the χ-barrier could, in principle, cross the barrier, if they found a way to change their momentum by the large amount required to jump into an altogether different valley, and under the same conditions electrons might also tunnel through the barrier. If no such momentum change can take place, the electrons will be reflected and the impedance of the junction will be high in either direction, at least until voltages have been reached that are sufficient to overcome the entire height of the χ-barrier, at which point direct injection into the (100) satellite valleys of the nGaAs will take place.

If absolutely no momentum exchange were possible at the junction, and assuming there were no normal conduction band discontinuity $\Delta\epsilon_c = 0$, the current-voltage characteristic of the nSi-nGaAs heterojunction of FIG. 12B would look as the solid line in FIG. 13. The most immediately useful application for this type of heterojunction that would inject heavily into a higher-lying valley, (100) of nGaAs, rather than into the lowest conduction band valley, (000) of GaAs; could again be for the source electrode of a BNC semiconductor as discussed previously. This follows since the bulk negative conductivity of n-GaAs and other types flows from the field-induced transfer of electrons from the (000) central main valley to the high (100) satellite valleys as discussed previously in connection with FIGS. 1 and 2 in particular.

Another interesting conceptual use for a χ-junction would be the following. Since, in reality the momentum exchange at the interface junction will never be completely forbidden any scattering processes, by phonons, impurities, other electrons, or by lattice imperfections (dislocations), may assist such an exchange. As a result, there will always be a finite conductivity before the upper-valley injection sets in. By increasing this finite conductivity externally, e.g. feedback or simply increased current it is conceptually feasible to increase the momentum exchange at the interface for the electrons populating the

Figure B.165: Herbert Kroemer invented III-V semiconductor heterostructures in 1966.



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(100) conduction band bottom of the nSi (low mobility high effective mass) such that they transfer into the (000) main valley of the nGaAs (high mobility-low effective mass) prior to the onset of injection into the higher satellite valleys of the wide gap partner. The result of this process would produce a negative resistance as shown in the dashed line of FIG. 13. Both electron-electron scattering and multiple phonon processes could lead to such a negative resistance at high current values and low voltages. Standard Si technology may be used to prepare the χ-junction in conjunction with the more recently developed epitaxial GaAs techniques. See, by way of example, R. S. Wagner and W. C. Ellis, "Vapor-Liquid-Solid Mechanism of Single Crystal Growth," Appl. Phys. Lett., vol. 4, pp. 89–90, March 1964 and the previously cited article by D. Effer entitled "Epitaxial Growth of Doped and Pure GaAs in an Open Flow System," J. Electrochemical Soc., vol. 112, No. 10, 1020 (1965).

In brief summary then, the present invention teaches several novel ways of obtaining improved control over the traveling space charge instabilities associated with the BNC semiconductor. The techniques include appropriate narrow to wide gap resistivity types; wide to narrow gap for direct injection; χ-junction; and resistivity gradients in bulk material itself.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A semiconductor microwave oscillator device comprising: an active element including a main body of semiconductor material characterized by having a drift velocity vs. electric field dependence with a region of negative differential mobility, said semiconductor main body being disposed between source and drain electrodes, and further characterized by generating internal traveling space charge domains upon being biased in its region of negative differential mobility, said semiconductor device being provided with means for predetermining the type of traveling space charge mode, said means comprising a heterojunction source control electrode, characterized by being made from a semiconductor material having a resistivity

$$\rho_h > \rho_B$$

where ρ_h is the resistivity of said heterojunction control electrode material, and ρ_B is the resistivity of said main body semiconductor, said heterojunction control electrode being further characterized by having a positive mobility over the operating range of the device.

2. The semiconductor microwave oscillator defined in claim **1** wherein said heterojunction source electrode is GaP and said semiconductor main body is n-type GaAs.

3. The semiconductor microwave oscillator defined in claim **1** wherein said heterojunction source electrode is Si and said semiconductor main body is n-type GaAs.

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4. A semiconductor microwave oscillator device comprising a main body of semiconductor material characterized by having a drift velocity vs. electric field dependence with a region of negative differential mobility, said semiconductor main body being disposed between source and drain electrodes, and further characterized by generating internal traveling space charge domains upon being biased in its region of negative differential mobility, said semiconductor device being provided with means for predetermining the type of traveling space charge mode which will propagate between said source and drain electrodes, said means for predetermining comprising a resistivity gradient in said main body in the direction of electron flow between said source and drain electrodes, said resistivity gradient falling within the range of 1% to 20% of the average resistivity of the main semiconductor body.

5. The device defined in claim **4** wherein said resistivity gradient is positive in the direction of propagation of said traveling space charge mode thereby causing formation of an accumulation mode.

6. The device defined in claim **4** wherein said resistivity gradient is negative in the direction of propagation of said traveling space charge mode thereby causing formation of a dipole mode.

7. A semiconductor microwave oscillator device comprising an active element including a main body of semiconductor material characterized by having a drift velocity vs. electric field dependence with a region of negative differential mobility, said semiconductor main body being disposed between source and drain electrodes, and further characterized by generating internal traveling space charge domains upon being biased in its region of negative differential mobility, said semiconductor device being provided with means for predetermining the type of traveling space charge mode which will propagate, said means for predetermining being a heterojunction source control electrode, said heterojunction source control electrode being an n-type semiconductor having a larger forbidden band gap than the forbidden gap of said body n-type semiconductor material.

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JAMES D. KALLAM, Primary Examiner

J. D. CRAIG, Assistant Examiner

U.S. Cl. X.R.

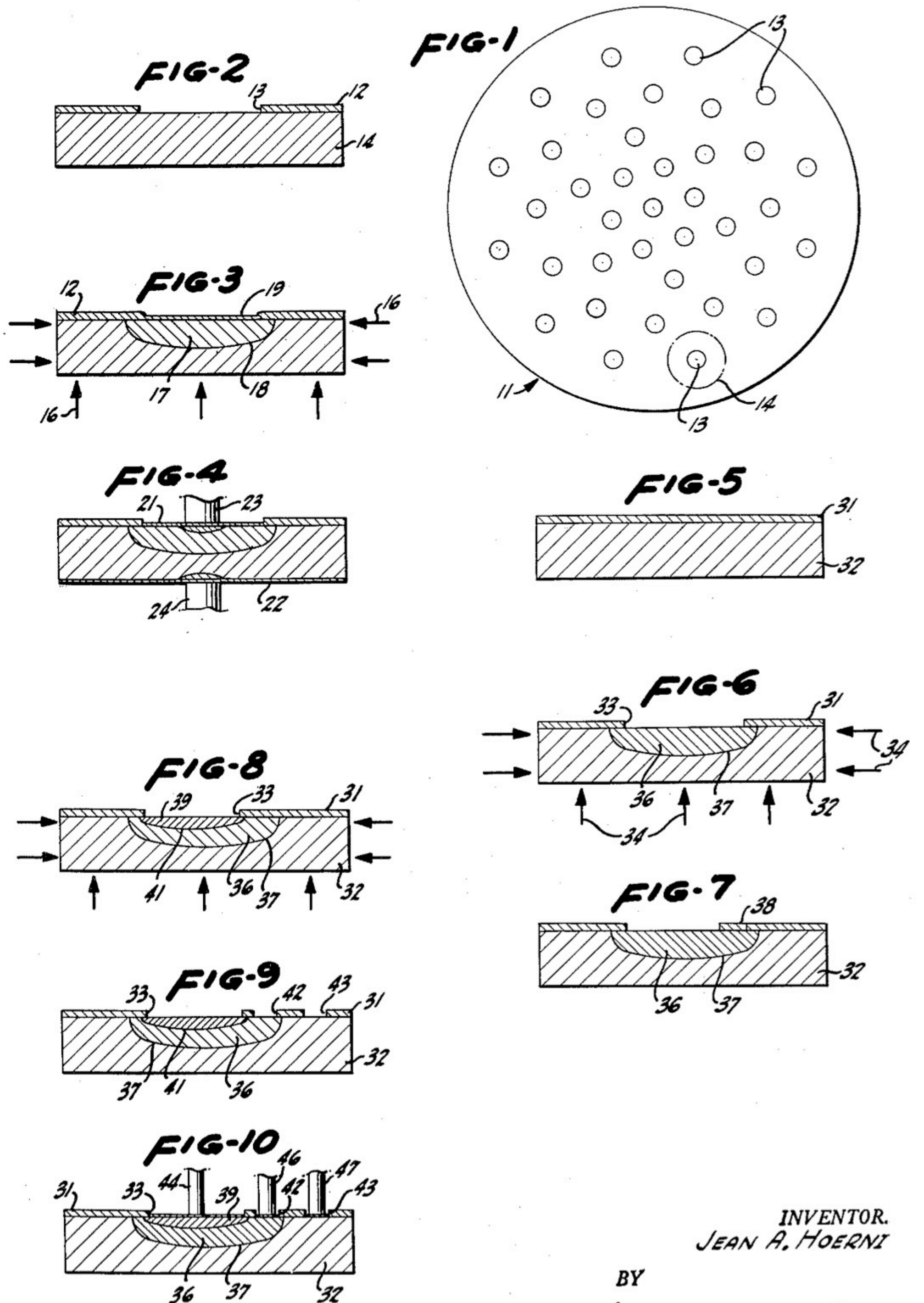
331—107

Figure B.166: Herbert Kroemer invented III-V semiconductor heterostructures in 1966.

March 20, 1962 J. A. HOERNI **3,025,589**

METHOD OF MANUFACTURING SEMICONDUCTOR DEVICES

Filed May 1, 1959



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BY

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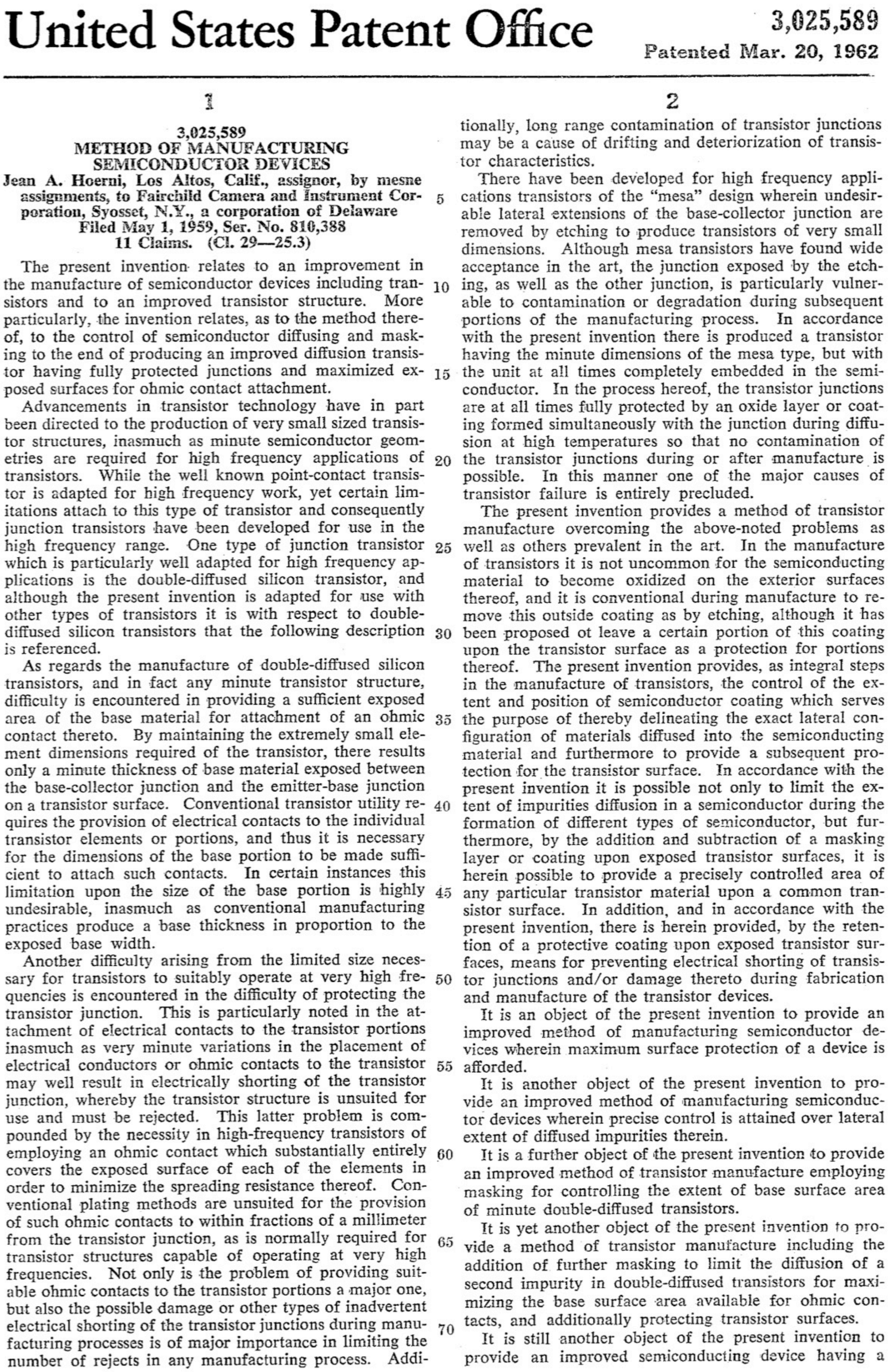
ATTORNEYS

Figure B.167: Jean Hoerni invented methods of manufacturing silicon transistors.



United States Patent Office

3,025,589

Patented Mar. 20, 1962

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METHOD OF MANUFACTURING SEMICONDUCTOR DEVICES

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Filed May 1, 1959, Ser. No. 810,388

11 Claims. (Cl. 29—25.3)

The present invention relates to an improvement in the manufacture of semiconductor devices including transistors and to an improved transistor structure. More particularly, the invention relates, as to the method thereof, to the control of semiconductor diffusing and masking to the end of producing an improved diffusion transistor having fully protected junctions and maximized exposed surfaces for ohmic contact attachment.

Advancements in transistor technology have in part been directed to the production of very small sized transistor structures, inasmuch as minute semiconductor geometries are required for high frequency applications of transistors. While the well known point-contact transistor is adapted for high frequency work, yet certain limitations attach to this type of transistor and consequently junction transistors have been developed for use in the high frequency range. One type of junction transistor which is particularly well adapted for high frequency applications is the double-diffused silicon transistor, and although the present invention is adapted for use with other types of transistors it is with respect to double-diffused silicon transistors that the following description is referenced.

As regards the manufacture of double-diffused silicon transistors, and in fact any minute transistor structure, difficulty is encountered in providing a sufficient exposed area of the base material for attachment of an ohmic contact thereto. By maintaining the extremely small element dimensions required of the transistor, there results only a minute thickness of base material exposed between the base-collector junction and the emitter-base junction on a transistor surface. Conventional transistor utility requires the provision of electrical contacts to the individual transistor elements or portions, and thus it is necessary for the dimensions of the base portion to be made sufficient to attach such contacts. In certain instances this limitation upon the size of the base portion is highly undesirable, inasmuch as conventional manufacturing practices produce a base thickness in proportion to the exposed base width.

Another difficulty arising from the limited size necessary for transistors to suitably operate at very high frequencies is encountered in the difficulty of protecting the transistor junction. This is particularly noted in the attachment of electrical contacts to the transistor portions inasmuch as very minute variations in the placement of electrical conductors or ohmic contacts to the transistor may well result in electrically shorting of the transistor junction, whereby the transistor structure is unsuited for use and must be rejected. This latter problem is compounded by the necessity in high-frequency transistors of employing an ohmic contact which substantially entirely covers the exposed surface of each of the elements in order to minimize the spreading resistance thereof. Conventional plating methods are unsuited for the provision of such ohmic contacts to within fractions of a millimeter from the transistor junction, as is normally required for transistor structures capable of operating at very high frequencies. Not only is the problem of providing suitable ohmic contacts to the transistor portions a major one, but also the possible damage or other types of inadvertent electrical shorting of the transistor junctions during manufacturing processes is of major importance in limiting the number of rejects in any manufacturing process. Additionally, long range contamination of transistor junctions may be a cause of drifting and deteriorization of transistor characteristics.

There have been developed for high frequency applications transistors of the "mesa" design wherein undesirable lateral extensions of the base-collector junction are removed by etching to produce transistors of very small dimensions. Although mesa transistors have found wide acceptance in the art, the junction exposed by the etching, as well as the other junction, is particularly vulnerable to contamination or degradation during subsequent portions of the manufacturing process. In accordance with the present invention there is produced a transistor having the minute dimensions of the mesa type, but with the unit at all times completely embedded in the semiconductor. In the process hereof, the transistor junctions are at all times fully protected by an oxide layer or coating formed simultaneously with the junction during diffusion at high temperatures so that no contamination of the transistor junctions during or after manufacture is possible. In this manner one of the major causes of transistor failure is entirely precluded.

The present invention provides a method of transistor manufacture overcoming the above-noted problems as well as others prevalent in the art. In the manufacture of transistors it is not uncommon for the semiconducting material to become oxidized on the exterior surfaces thereof, and it is conventional during manufacture to remove this outside coating as by etching, although it has been proposed ot leave a certain portion of this coating upon the transistor surface as a protection for portions thereof. The present invention provides, as integral steps in the manufacture of transistors, the control of the extent and position of semiconductor coating which serves the purpose of thereby delineating the exact lateral configuration of materials diffused into the semiconducting material and furthermore to provide a subsequent protection for the transistor surface. In accordance with the present invention it is possible not only to limit the extent of impurities diffusion in a semiconductor during the formation of different types of semiconductor, but furthermore, by the addition and subtraction of a masking layer or coating upon exposed transistor surfaces, it is herein possible to provide a precisely controlled area of any particular transistor material upon a common transistor surface. In addition, and in accordance with the present invention, there is herein provided, by the retention of a protective coating upon exposed transistor surfaces, means for preventing electrical shorting of transistor junctions and/or damage thereto during fabrication and manufacture of the transistor devices.

It is an object of the present invention to provide an improved method of manufacturing semiconductor devices wherein maximum surface protection of a device is afforded.

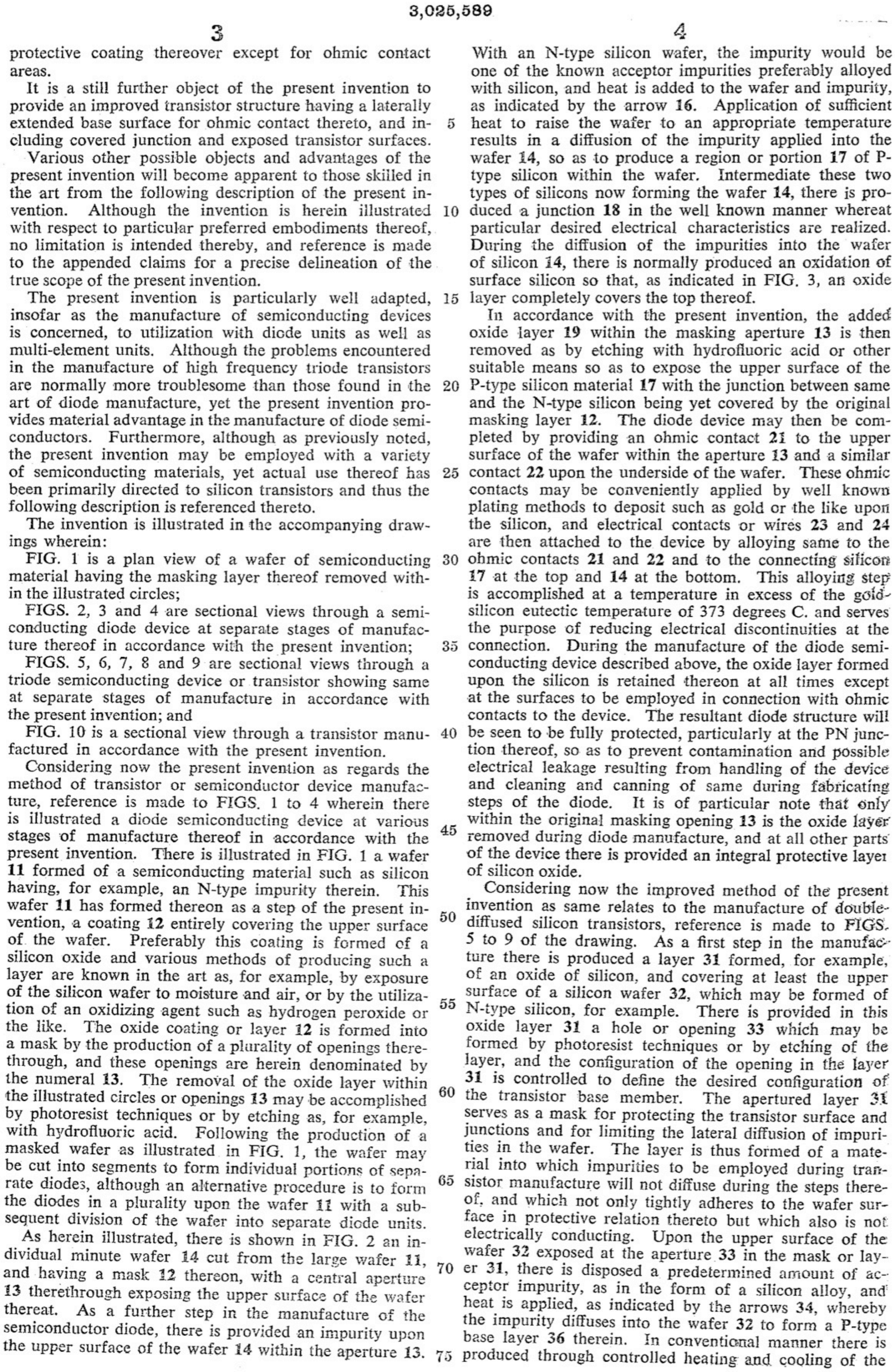
It is another object of the present invention to provide an improved method of manufacturing semiconductor devices wherein precise control is attained over lateral extent of diffused impurities therein.

It is a further object of the present invention to provide an improved method of transistor manufacture employing masking for controlling the extent of base surface area of minute double-diffused transistors.

It is yet another object of the present invention to provide a method of transistor manufacture including the addition of further masking to limit the diffusion of a second impurity in double-diffused transistors for maximizing the base surface area available for ohmic contacts, and additionally protecting transistor surfaces.

It is still another object of the present invention to provide an improved semiconducting device having a

Figure B.168: Jean Hoerni invented methods of manufacturing silicon transistors.



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protective coating thereover except for ohmic contact areas.

It is a still further object of the present invention to provide an improved transistor structure having a laterally extended base surface for ohmic contact thereto, and including covered junction and exposed transistor surfaces.

Various other possible objects and advantages of the present invention will become apparent to those skilled in the art from the following description of the present invention. Although the invention is herein illustrated with respect to particular preferred embodiments thereof, no limitation is intended thereby, and reference is made to the appended claims for a precise delineation of the true scope of the present invention.

The present invention is particularly well adapted, insofar as the manufacture of semiconducting devices is concerned, to utilization with diode units as well as multi-element units. Although the problems encountered in the manufacture of high frequency triode transistors are normally more troublesome than those found in the art of diode manufacture, yet the present invention provides material advantage in the manufacture of diode semiconductors. Furthermore, although as previously noted, the present invention may be employed with a variety of semiconducting materials, yet actual use thereof has been primarily directed to silicon transistors and thus the following description is referenced thereto.

The invention is illustrated in the accompanying drawings wherein:

FIG. 1 is a plan view of a wafer of semiconducting material having the masking layer thereof removed within the illustrated circles;

FIGS. 2, 3 and 4 are sectional views through a semiconducting diode device at separate stages of manufacture thereof in accordance with the present invention;

FIGS. 5, 6, 7, 8 and 9 are sectional views through a triode semiconducting device or transistor showing same at separate stages of manufacture in accordance with the present invention; and

FIG. 10 is a sectional view through a transistor manufactured in accordance with the present invention.

Considering now the present invention as regards the method of transistor or semiconductor device manufacture, reference is made to FIGS. 1 to 4 wherein there is illustrated a diode semiconducting device at various stages of manufacture thereof in accordance with the present invention. There is illustrated in FIG. 1 a wafer **11** formed of a semiconducting material such as silicon having, for example, an N-type impurity therein. This wafer **11** has formed thereon as a step of the present invention, a coating **12** entirely covering the upper surface of the wafer. Preferably this coating is formed of a silicon oxide and various methods of producing such a layer are known in the art as, for example, by exposure of the silicon wafer to moisture and air, or by the utilization of an oxidizing agent such as hydrogen peroxide or the like. The oxide coating or layer **12** is formed into a mask by the production of a plurality of openings therethrough, and these openings are herein denominated by the numeral **13**. The removal of the oxide layer within the illustrated circles or openings **13** may be accomplished by photoresist techniques or by etching as, for example, with hydrofluoric acid. Following the production of a masked wafer as illustrated in FIG. 1, the wafer may be cut into segments to form individual portions of separate diodes, although an alternative procedure is to form the diodes in a plurality upon the wafer **11** with a subsequent division of the wafer into separate diode units.

As herein illustrated, there is shown in FIG. 2 an individual minute wafer **14** cut from the large wafer **11**, and having a mask **12** thereon, with a central aperture **13** therethrough exposing the upper surface of the wafer thereat. As a further step in the manufacture of the semiconductor diode, there is provided an impurity upon the upper surface of the wafer **14** within the aperture **13**.

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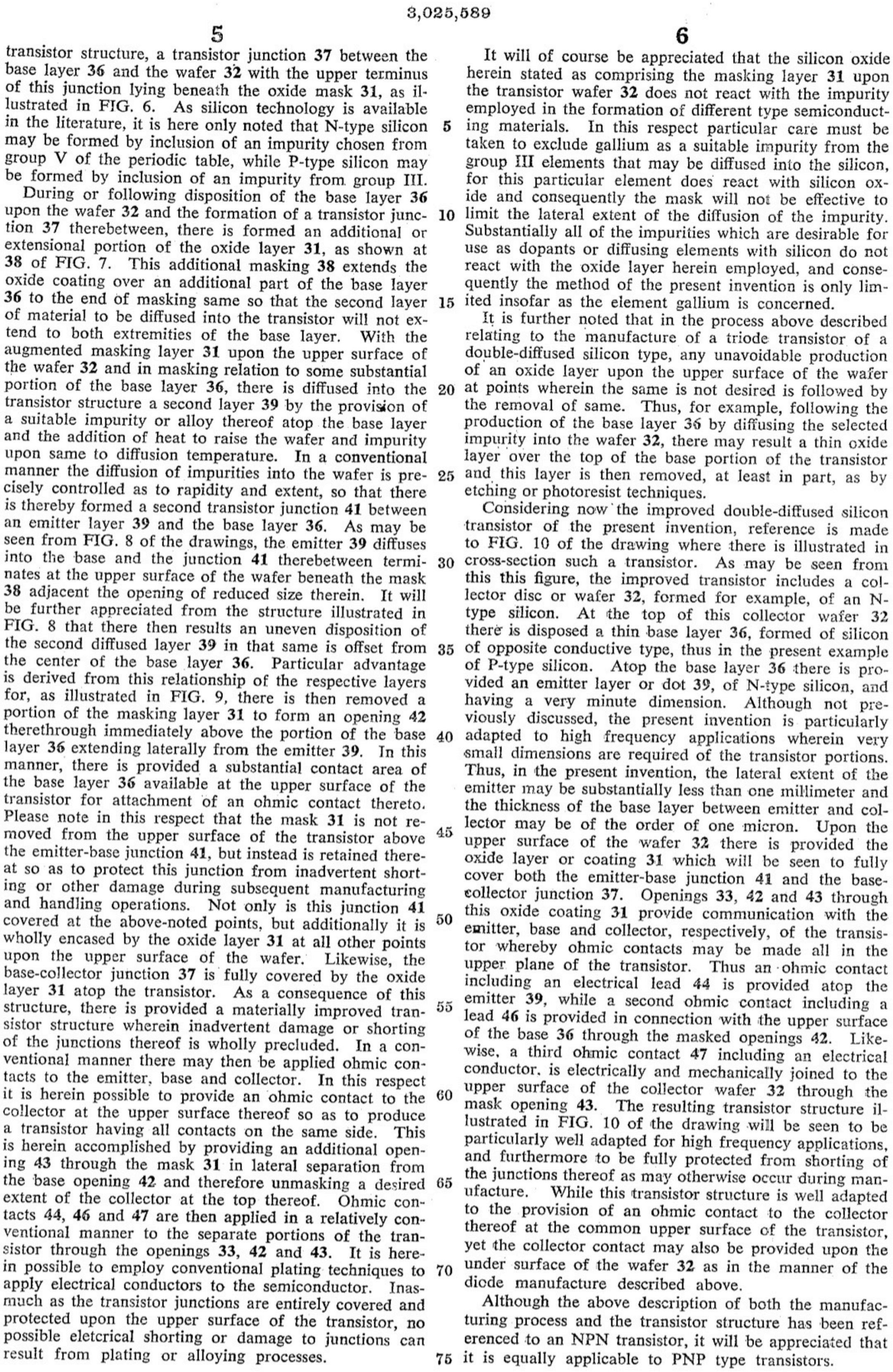
With an N-type silicon wafer, the impurity would be one of the known acceptor impurities preferably alloyed with silicon, and heat is added to the wafer and impurity, as indicated by the arrow **16**. Application of sufficient heat to raise the wafer to an appropriate temperature results in a diffusion of the impurity applied into the wafer **14**, so as to produce a region or portion **17** of P-type silicon within the wafer. Intermediate these two types of silicons now forming the wafer **14**, there is produced a junction **18** in the well known manner whereat particular desired electrical characteristics are realized. During the diffusion of the impurities into the wafer of silicon **14**, there is normally produced an oxidation of surface silicon so that, as indicated in FIG. 3, an oxide layer completely covers the top thereof.

In accordance with the present invention, the added oxide layer **19** within the masking aperture **13** is then removed as by etching with hydrofluoric acid or other suitable means so as to expose the upper surface of the P-type silicon material **17** with the junction between same and the N-type silicon being yet covered by the original masking layer **12**. The diode device may then be completed by providing an ohmic contact **21** to the upper surface of the wafer within the aperture **13** and a similar contact **22** upon the underside of the wafer. These ohmic contacts may be conveniently applied by well known plating methods to deposit such as gold or the like upon the silicon, and electrical contacts or wires **23** and **24** are then attached to the device by alloying same to the ohmic contacts **21** and **22** and to the connecting silicon **17** at the top and **14** at the bottom. This alloying step is accomplished at a temperature in excess of the gold-silicon eutectic temperature of 373 degrees C. and serves the purpose of reducing electrical discontinuities at the connection. During the manufacture of the diode semiconducting device described above, the oxide layer formed upon the silicon is retained thereon at all times except at the surfaces to be employed in connection with ohmic contacts to the device. The resultant diode structure will be seen to be fully protected, particularly at the PN junction thereof, so as to prevent contamination and possible electrical leakage resulting from handling of the device and cleaning and canning of same during fabricating steps of the diode. It is of particular note that only within the original masking opening **13** is the oxide layer removed during diode manufacture, and at all other parts of the device there is provided an integral protective layer of silicon oxide.

Considering now the improved method of the present invention as same relates to the manufacture of double-diffused silicon transistors, reference is made to FIGS. 5 to 9 of the drawing. As a first step in the manufacture there is produced a layer **31** formed, for example, of an oxide of silicon, and covering at least the upper surface of a silicon wafer **32**, which may be formed of N-type silicon, for example. There is provided in this oxide layer **31** a hole or opening **33** which may be formed by photoresist techniques or by etching of the layer, and the configuration of the opening in the layer **31** is controlled to define the desired configuration of the transistor base member. The apertured layer **31** serves as a mask for protecting the transistor surface and junctions and for limiting the lateral diffusion of impurities in the wafer. The layer is thus formed of a material into which impurities to be employed during transistor manufacture will not diffuse during the steps thereof, and which not only tightly adheres to the wafer surface in protective relation thereto but which also is not electrically conducting. Upon the upper surface of the wafer **32** exposed at the aperture **33** in the mask or layer **31**, there is disposed a predetermined amount of acceptor impurity, as in the form of a silicon alloy, and heat is applied, as indicated by the arrows **34**, whereby the impurity diffuses into the wafer **32** to form a P-type base layer **36** therein. In conventional manner there is produced through controlled heating and cooling of the

Figure B.169: Jean Hoerni invented methods of manufacturing silicon transistors.



transistor structure, a transistor junction **37** between the base layer **36** and the wafer **32** with the upper terminus of this junction lying beneath the oxide mask **31**, as illustrated in FIG. 6. As silicon technology is available in the literature, it is here only noted that N-type silicon may be formed by inclusion of an impurity chosen from group V of the periodic table, while P-type silicon may be formed by inclusion of an impurity from group III.

During or following disposition of the base layer **36** upon the wafer **32** and the formation of a transistor junction **37** therebetween, there is formed an additional or extensional portion of the oxide layer **31**, as shown at **38** of FIG. 7. This additional masking **38** extends the oxide coating over an additional part of the base layer **36** to the end of masking same so that the second layer of material to be diffused into the transistor will not extend to both extremities of the base layer. With the augmented masking layer **31** upon the upper surface of the wafer **32** and in masking relation to some substantial portion of the base layer **36**, there is diffused into the transistor structure a second layer **39** by the provision of a suitable impurity or alloy thereof atop the base layer and the addition of heat to raise the wafer and impurity upon same to diffusion temperature. In a conventional manner the diffusion of impurities into the wafer is precisely controlled as to rapidity and extent, so that there is thereby formed a second transistor junction **41** between an emitter layer **39** and the base layer **36**. As may be seen from FIG. 8 of the drawings, the emitter **39** diffuses into the base and the junction **41** therebetween terminates at the upper surface of the wafer beneath the mask **38** adjacent the opening of reduced size therein. It will be further appreciated from the structure illustrated in FIG. 8 that there then results an uneven disposition of the second diffused layer **39** in that same is offset from the center of the base layer **36**. Particular advantage is derived from this relationship of the respective layers for, as illustrated in FIG. 9, there is then removed a portion of the masking layer **31** to form an opening **42** therethrough immediately above the portion of the base layer **36** extending laterally from the emitter **39**. In this manner, there is provided a substantial contact area of the base layer **36** available at the upper surface of the transistor for attachment of an ohmic contact thereto. Please note in this respect that the mask **31** is not removed from the upper surface of the transistor above the emitter-base junction **41**, but instead is retained thereat so as to protect this junction from inadvertent shorting or other damage during subsequent manufacturing and handling operations. Not only is this junction **41** covered at the above-noted points, but additionally it is wholly encased by the oxide layer **31** at all other points upon the upper surface of the wafer. Likewise, the base-collector junction **37** is fully covered by the oxide layer **31** atop the transistor. As a consequence of this structure, there is provided a materially improved transistor structure wherein inadvertent damage or shorting of the junctions thereof is wholly precluded. In a conventional manner there may then be applied ohmic contacts to the emitter, base and collector. In this respect it is herein possible to provide an ohmic contact to the collector at the upper surface thereof so as to produce a transistor having all contacts on the same side. This is herein accomplished by providing an additional opening **43** through the mask **31** in lateral separation from the base opening **42** and therefore unmasking a desired extent of the collector at the top thereof. Ohmic contacts **44**, **46** and **47** are then applied in a relatively conventional manner to the separate portions of the transistor through the openings **33**, **42** and **43**. It is herein possible to employ conventional plating techniques to apply electrical conductors to the semiconductor. Inasmuch as the transistor junctions are entirely covered and protected upon the upper surface of the transistor, no possible eletcrical shorting or damage to junctions can result from plating or alloying processes.

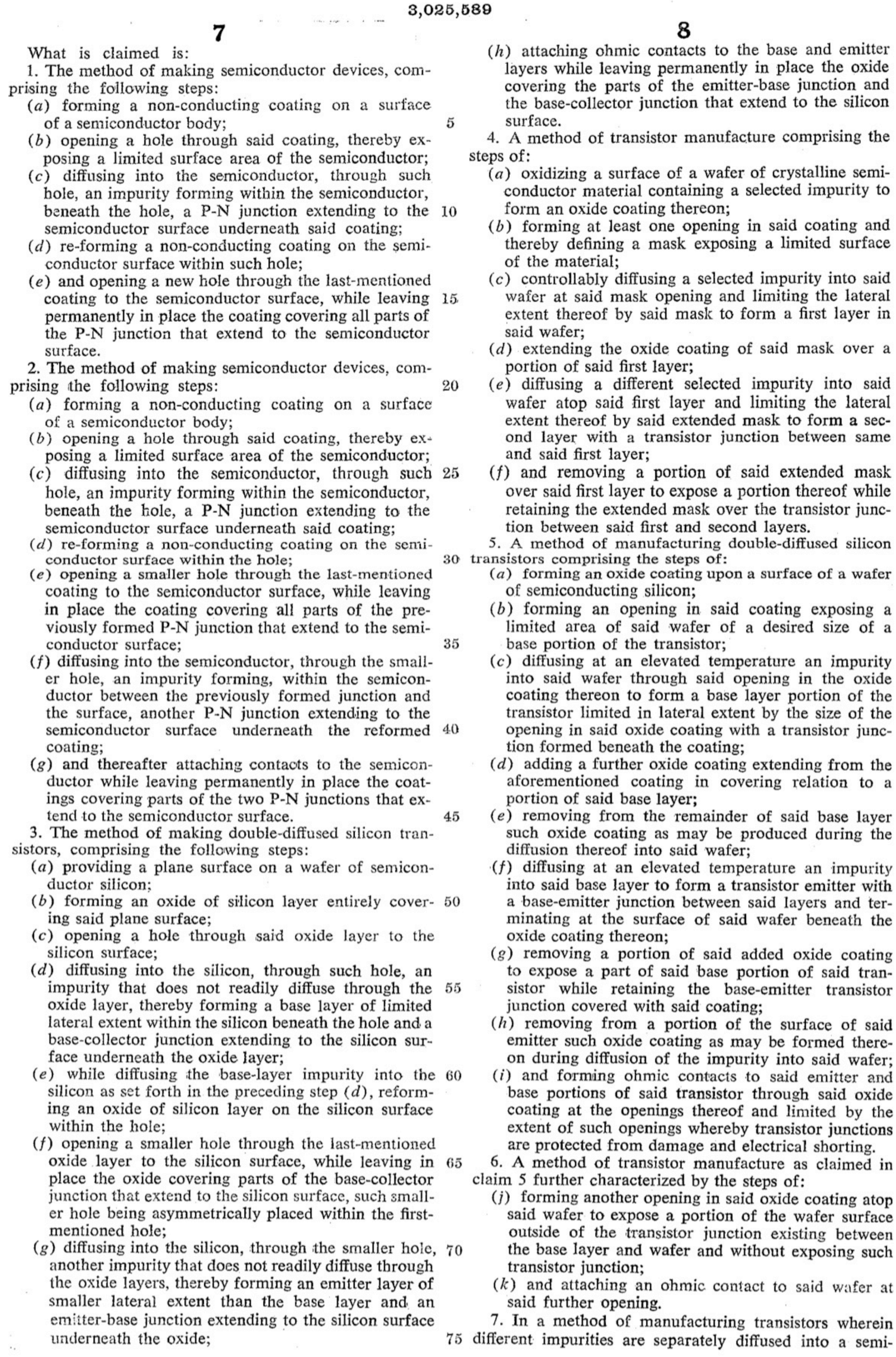
It will of course be appreciated that the silicon oxide herein stated as comprising the masking layer **31** upon the transistor wafer **32** does not react with the impurity employed in the formation of different type semiconducting materials. In this respect particular care must be taken to exclude gallium as a suitable impurity from the group III elements that may be diffused into the silicon, for this particular element does react with silicon oxide and consequently the mask will not be effective to limit the lateral extent of the diffusion of the impurity. Substantially all of the impurities which are desirable for use as dopants or diffusing elements with silicon do not react with the oxide layer herein employed, and consequently the method of the present invention is only limited insofar as the element gallium is concerned.

It is further noted that in the process above described relating to the manufacture of a triode transistor of a double-diffused silicon type, any unavoidable production of an oxide layer upon the upper surface of the wafer at points wherein the same is not desired is followed by the removal of same. Thus, for example, following the production of the base layer **36** by diffusing the selected impurity into the wafer **32**, there may result a thin oxide layer over the top of the base portion of the transistor and this layer is then removed, at least in part, as by etching or photoresist techniques.

Considering now the improved double-diffused silicon transistor of the present invention, reference is made to FIG. 10 of the drawing where there is illustrated in cross-section such a transistor. As may be seen from this this figure, the improved transistor includes a collector disc or wafer **32**, formed for example, of an N-type silicon. At the top of this collector wafer **32** there is disposed a thin base layer **36**, formed of silicon of opposite conductive type, thus in the present example of P-type silicon. Atop the base layer **36** there is provided an emitter layer or dot **39**, of N-type silicon, and having a very minute dimension. Although not previously discussed, the present invention is particularly adapted to high frequency applications wherein very small dimensions are required of the transistor portions. Thus, in the present invention, the lateral extent of the emitter may be substantially less than one millimeter and the thickness of the base layer between emitter and collector may be of the order of one micron. Upon the upper surface of the wafer **32** there is provided the oxide layer or coating **31** which will be seen to fully cover both the emitter-base junction **41** and the base-collector junction **37**. Openings **33**, **42** and **43** through this oxide coating **31** provide communication with the emitter, base and collector, respectively, of the transistor whereby ohmic contacts may be made all in the upper plane of the transistor. Thus an ohmic contact including an electrical lead **44** is provided atop the emitter **39**, while a second ohmic contact including a lead **46** is provided in connection with the upper surface of the base **36** through the masked openings **42**. Likewise, a third ohmic contact **47** including an electrical conductor, is electrically and mechanically joined to the upper surface of the collector wafer **32** through the mask opening **43**. The resulting transistor structure illustrated in FIG. 10 of the drawing will be seen to be particularly well adapted for high frequency applications, and furthermore to be fully protected from shorting of the junctions thereof as may otherwise occur during manufacture. While this transistor structure is well adapted to the provision of an ohmic contact to the collector thereof at the common upper surface of the transistor, yet the collector contact may also be provided upon the under surface of the wafer **32** as in the manner of the diode manufacture described above.

Although the above description of both the manufacturing process and the transistor structure has been referenced to an NPN transistor, it will be appreciated that it is equally applicable to PNP type transistors.

Figure B.170: Jean Hoerni invented methods of manufacturing silicon transistors.



What is claimed is:

1. The method of making semiconductor devices, comprising the following steps:
   (*a*) forming a non-conducting coating on a surface of a semiconductor body;
   (*b*) opening a hole through said coating, thereby exposing a limited surface area of the semiconductor;
   (*c*) diffusing into the semiconductor, through such hole, an impurity forming within the semiconductor, beneath the hole, a P-N junction extending to the semiconductor surface underneath said coating;
   (*d*) re-forming a non-conducting coating on the semiconductor surface within such hole;
   (*e*) and opening a new hole through the last-mentioned coating to the semiconductor surface, while leaving permanently in place the coating covering all parts of the P-N junction that extend to the semiconductor surface.

2. The method of making semiconductor devices, comprising the following steps:
   (*a*) forming a non-conducting coating on a surface of a semiconductor body;
   (*b*) opening a hole through said coating, thereby exposing a limited surface area of the semiconductor;
   (*c*) diffusing into the semiconductor, through such hole, an impurity forming within the semiconductor, beneath the hole, a P-N junction extending to the semiconductor surface underneath said coating;
   (*d*) re-forming a non-conducting coating on the semiconductor surface within the hole;
   (*e*) opening a smaller hole through the last-mentioned coating to the semiconductor surface, while leaving in place the coating covering all parts of the previously formed P-N junction that extend to the semiconductor surface;
   (*f*) diffusing into the semiconductor, through the smaller hole, an impurity forming, within the semiconductor between the previously formed junction and the surface, another P-N junction extending to the semiconductor surface underneath the reformed coating;
   (*g*) and thereafter attaching contacts to the semiconductor while leaving permanently in place the coatings covering parts of the two P-N junctions that extend to the semiconductor surface.

3. The method of making double-diffused silicon transistors, comprising the following steps:
   (*a*) providing a plane surface on a wafer of semiconductor silicon;
   (*b*) forming an oxide of silicon layer entirely covering said plane surface;
   (*c*) opening a hole through said oxide layer to the silicon surface;
   (*d*) diffusing into the silicon, through such hole, an impurity that does not readily diffuse through the oxide layer, thereby forming a base layer of limited lateral extent within the silicon beneath the hole and a base-collector junction extending to the silicon surface underneath the oxide layer;
   (*e*) while diffusing the base-layer impurity into the silicon as set forth in the preceding step (*d*), reforming an oxide of silicon layer on the silicon surface within the hole;
   (*f*) opening a smaller hole through the last-mentioned oxide layer to the silicon surface, while leaving in place the oxide covering parts of the base-collector junction that extend to the silicon surface, such smaller hole being asymmetrically placed within the first-mentioned hole;
   (*g*) diffusing into the silicon, through the smaller hole, another impurity that does not readily diffuse through the oxide layers, thereby forming an emitter layer of smaller lateral extent than the base layer and an emitter-base junction extending to the silicon surface underneath the oxide;
   (*h*) attaching ohmic contacts to the base and emitter layers while leaving permanently in place the oxide covering the parts of the emitter-base junction and the base-collector junction that extend to the silicon surface.

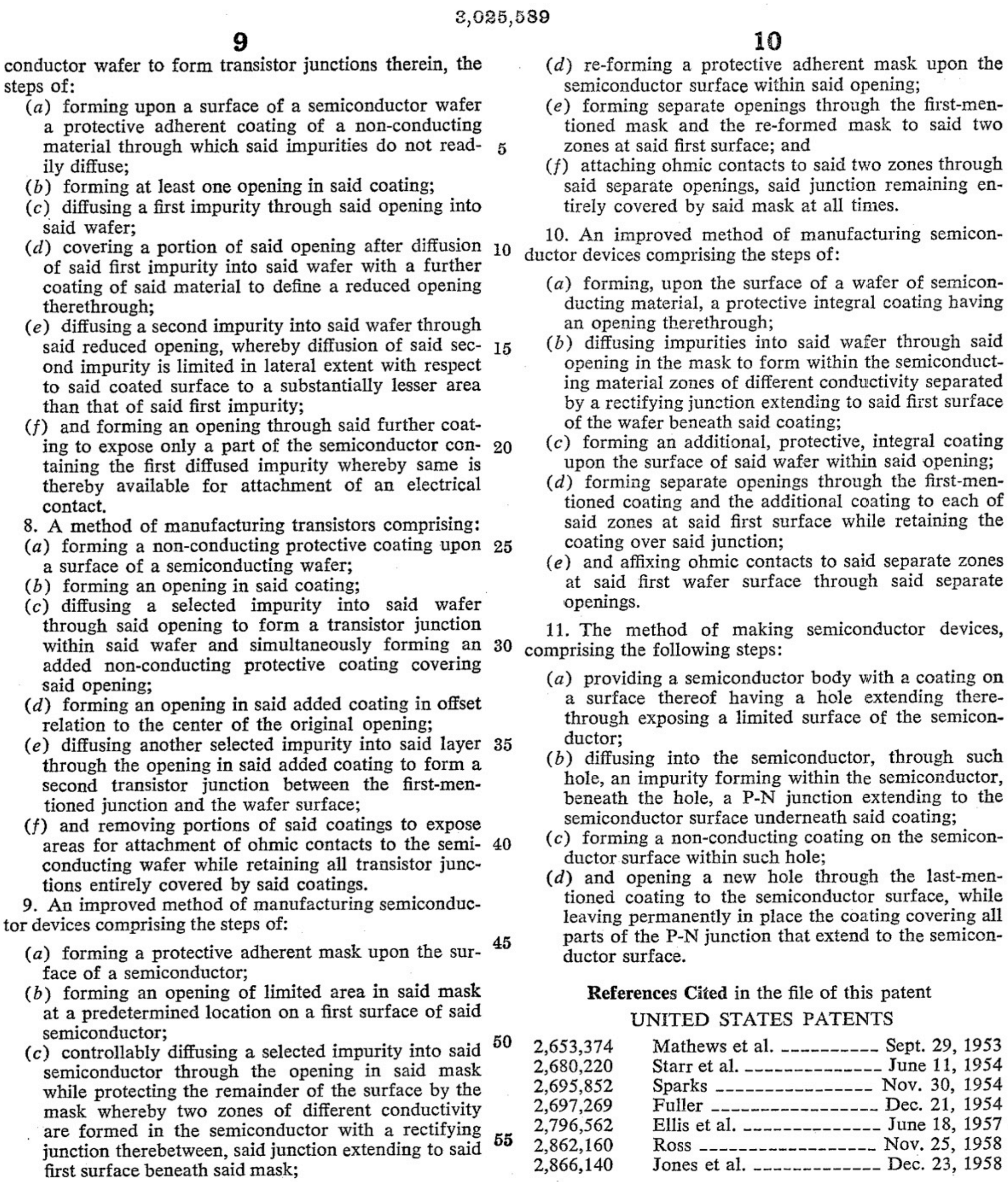
4. A method of transistor manufacture comprising the steps of:
   (*a*) oxidizing a surface of a wafer of crystalline semiconductor material containing a selected impurity to form an oxide coating thereon;
   (*b*) forming at least one opening in said coating and thereby defining a mask exposing a limited surface of the material;
   (*c*) controllably diffusing a selected impurity into said wafer at said mask opening and limiting the lateral extent thereof by said mask to form a first layer in said wafer;
   (*d*) extending the oxide coating of said mask over a portion of said first layer;
   (*e*) diffusing a different selected impurity into said wafer atop said first layer and limiting the lateral extent thereof by said extended mask to form a second layer with a transistor junction between same and said first layer;
   (*f*) and removing a portion of said extended mask over said first layer to expose a portion thereof while retaining the extended mask over the transistor junction between said first and second layers.

5. A method of manufacturing double-diffused silicon transistors comprising the steps of:
   (*a*) forming an oxide coating upon a surface of a wafer of semiconducting silicon;
   (*b*) forming an opening in said coating exposing a limited area of said wafer of a desired size of a base portion of the transistor;
   (*c*) diffusing at an elevated temperature an impurity into said wafer through said opening in the oxide coating thereon to form a base layer portion of the transistor limited in lateral extent by the size of the opening in said oxide coating with a transistor junction formed beneath the coating;
   (*d*) adding a further oxide coating extending from the aforementioned coating in covering relation to a portion of said base layer;
   (*e*) removing from the remainder of said base layer such oxide coating as may be produced during the diffusion thereof into said wafer;
   (*f*) diffusing at an elevated temperature an impurity into said base layer to form a transistor emitter with a base-emitter junction between said layers and terminating at the surface of said wafer beneath the oxide coating thereon;
   (*g*) removing a portion of said added oxide coating to expose a part of said base portion of said transistor while retaining the base-emitter transistor junction covered with said coating;
   (*h*) removing from a portion of the surface of said emitter such oxide coating as may be formed thereon during diffusion of the impurity into said wafer;
   (*i*) and forming ohmic contacts to said emitter and base portions of said transistor through said oxide coating at the openings thereof and limited by the extent of such openings whereby transistor junctions are protected from damage and electrical shorting.

6. A method of transistor manufacture as claimed in claim 5 further characterized by the steps of:
   (*j*) forming another opening in said oxide coating atop said wafer to expose a portion of the wafer surface outside of the transistor junction existing between the base layer and wafer and without exposing such transistor junction;
   (*k*) and attaching an ohmic contact to said wafer at said further opening.

7. In a method of manufacturing transistors wherein different impurities are separately diffused into a semi-

Figure B.171: Jean Hoerni invented methods of manufacturing silicon transistors.



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conductor wafer to form transistor junctions therein, the steps of:

(*a*) forming upon a surface of a semiconductor wafer a protective adherent coating of a non-conducting material through which said impurities do not readily diffuse;
(*b*) forming at least one opening in said coating;
(*c*) diffusing a first impurity through said opening into said wafer;
(*d*) covering a portion of said opening after diffusion of said first impurity into said wafer with a further coating of said material to define a reduced opening therethrough;
(*e*) diffusing a second impurity into said wafer through said reduced opening, whereby diffusion of said second impurity is limited in lateral extent with respect to said coated surface to a substantially lesser area than that of said first impurity;
(*f*) and forming an opening through said further coating to expose only a part of the semiconductor containing the first diffused impurity whereby same is thereby available for attachment of an electrical contact.

8. A method of manufacturing transistors comprising:
(*a*) forming a non-conducting protective coating upon a surface of a semiconducting wafer;
(*b*) forming an opening in said coating;
(*c*) diffusing a selected impurity into said wafer through said opening to form a transistor junction within said wafer and simultaneously forming an added non-conducting protective coating covering said opening;
(*d*) forming an opening in said added coating in offset relation to the center of the original opening;
(*e*) diffusing another selected impurity into said layer through the opening in said added coating to form a second transistor junction between the first-mentioned junction and the wafer surface;
(*f*) and removing portions of said coatings to expose areas for attachment of ohmic contacts to the semiconducting wafer while retaining all transistor junctions entirely covered by said coatings.

9. An improved method of manufacturing semiconductor devices comprising the steps of:

(*a*) forming a protective adherent mask upon the surface of a semiconductor;
(*b*) forming an opening of limited area in said mask at a predetermined location on a first surface of said semiconductor;
(*c*) controllably diffusing a selected impurity into said semiconductor through the opening in said mask while protecting the remainder of the surface by the mask whereby two zones of different conductivity are formed in the semiconductor with a rectifying junction therebetween, said junction extending to said first surface beneath said mask;

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(*d*) re-forming a protective adherent mask upon the semiconductor surface within said opening;
(*e*) forming separate openings through the first-mentioned mask and the re-formed mask to said two zones at said first surface; and
(*f*) attaching ohmic contacts to said two zones through said separate openings, said junction remaining entirely covered by said mask at all times.

10. An improved method of manufacturing semiconductor devices comprising the steps of:

(*a*) forming, upon the surface of a wafer of semiconducting material, a protective integral coating having an opening therethrough;
(*b*) diffusing impurities into said wafer through said opening in the mask to form within the semiconducting material zones of different conductivity separated by a rectifying junction extending to said first surface of the wafer beneath said coating;
(*c*) forming an additional, protective, integral coating upon the surface of said wafer within said opening;
(*d*) forming separate openings through the first-mentioned coating and the additional coating to each of said zones at said first surface while retaining the coating over said junction;
(*e*) and affixing ohmic contacts to said separate zones at said first wafer surface through said separate openings.

11. The method of making semiconductor devices, comprising the following steps:

(*a*) providing a semiconductor body with a coating on a surface thereof having a hole extending therethrough exposing a limited surface of the semiconductor;
(*b*) diffusing into the semiconductor, through such hole, an impurity forming within the semiconductor, beneath the hole, a P-N junction extending to the semiconductor surface underneath said coating;
(*c*) forming a non-conducting coating on the semiconductor surface within such hole;
(*d*) and opening a new hole through the last-mentioned coating to the semiconductor surface, while leaving permanently in place the coating covering all parts of the P-N junction that extend to the semiconductor surface.

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Figure B.172: Jean Hoerni invented methods of manufacturing silicon transistors.

Nov. 13, 1962 J. A. HOERNI **3,064,167**

SEMICONDUCTOR DEVICE

Original Filed May 1, 1959

FIG-2

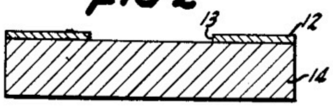


FIG-1

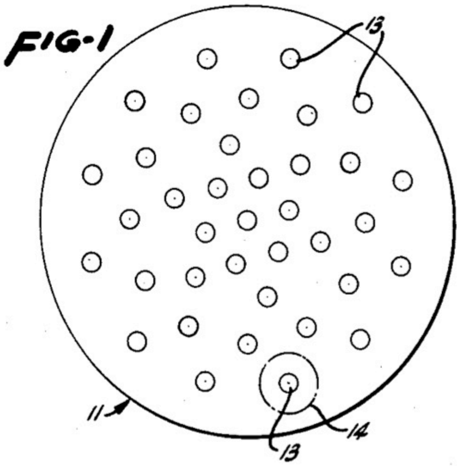


FIG-3

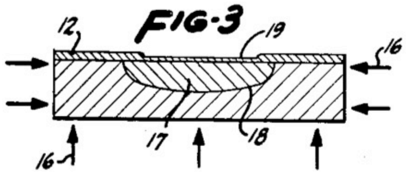


FIG-4

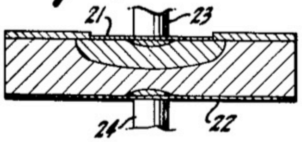


FIG-5

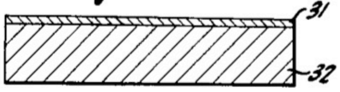


FIG-6

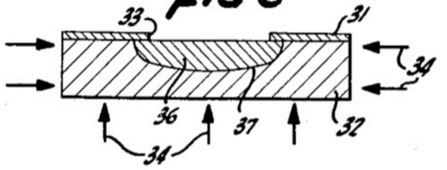


FIG-8

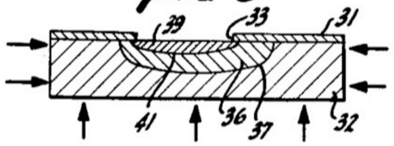


FIG-7

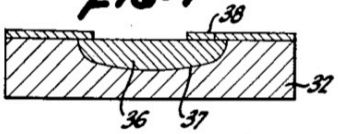


FIG-9

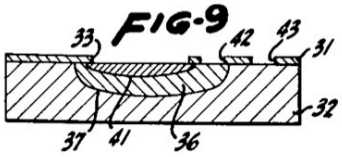
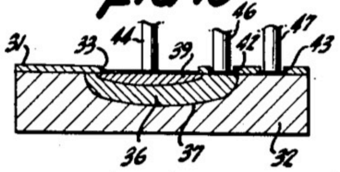


FIG-10



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BY

Lippincott, Ralls & Hendricson
ATTORNEYS

Figure B.173: Jean Hoerni invented methods of manufacturing silicon transistors.

United States Patent Office

3,064,167
Patented Nov. 13, 1962

3,064,167
SEMICONDUCTOR DEVICE
Jean A. Hoerni, Los Altos, Calif., assignor, by mesne assignments, to Fairchild Camera and Instrument Corporation, Syosset, N.Y., a corporation of Delaware
Original application May 1, 1959, Ser. No. 810,388. Divided and this application May 19, 1960, Ser. No. 30,256
6 Claims. (Cl. 317—234)

This application is a division of my copending application Serial No. 810,388, filed May 1, 1959, and now Patent No. 3,025,589.

The present invention relates to an improvement in semiconductor devices including transistors and to an improved transistor structure. More particularly, the invention relates to an improved diffusion transistor having fully protected junctions and maximized exposed surfaces for ohmic contact attachment.

Advancements in transistor technology have in part been directed to the production of very small sized transistor structures, inasmuch as minute semiconductor geometries are required for high frequency applications of transistors. While the well known point-contact transistor is adapted for high frequency work, yet certain limitations attach to this type of transistor and consequently junction transistors have been developed for use in the high frequency range. One type of junction transistor which is particularly well adapted for high frequency applications is the double-diffused silicon transistor, and although the present invention is adapted for use with other types of transistors it is with respect to double-diffused silicon transistors that the following description is referenced.

As regards the manufacture of double-diffused silicon transistors, and in fact any minute transistor structure, difficulty is encountered in providing a sufficient exposed area of the base material for attachment of an ohmic contact thereto. By maintaining the extremely small element dimensions required of the transistor, there results only a minute thickness of base material exposed between the base-collector junction and the emitter-base junction on a transistor surface. Conventional transistor utility requires the provision of electrical contacts to the individual transistor elements or portions, and thus it is necessary for the dimensions of the base portion to be made sufficient to attach such contacts. In certain instances this limitation upon the size of the base portion is highly undesirable, inasmuch as conventional manufacturing practices produce a base thickness in proportion to the exposed base width.

Another difficulty arising from the limited size necessary for transistors to suitably operate at very high frequencies is encountered in the difficulty of protecting the transistor junction. This is particularly noted in the attachment of electrical contacts to the transistor portions inasmuch as very minute variations in the placement of electrical conductors or ohmic contacts to the transistor may well result in electrically shorting of the transistor junction, whereby the transistor structure is unsuited for use and must be rejected. This latter problem is compounded by the necessity in high-frequency transistors of employing an ohmic contact which substantially entirely covers the exposed surface of each of the elements in order to minimize the spreading resistance thereof. Conventional plating methods are unsuited for the provision of such ohmic contacts to within fractions of a millimeter from the transistor junction, as is normally required for transistor structures capable of operating at very high frequencies. Not only is the problem of providing suitable ohmic contacts to the transistor portions a major one, but also the possible damage or other types of inadvertent electrical shorting of the transistor junctions during manufacturing processes is of major importance in limiting the number of rejects in any manufacturing process. Additionally, long range contamination of transistor junctions may be a cause of drifting and deterioration of transistor characteristics.

There have been developed for high frequency applications transistors of the "mesa" design wherein undesirable lateral extensions of the base-collector junction are removed by etching to produce transistors of very small dimensions. Although mesa transistors have found wide acceptance in the art, the junction exposed by the etching, as well as the other junction, is particularly vulnerable to contamination or degradation during subsequent portions of the manufacturing process. In accordance with the present invention there is produced a transistor having the minute dimensions of the mesa type, but with the transistor junctions at all times fully protected by an oxide layer or coating formed simultaneously with the junction during diffusion at high temperatures so that no contamination of the transistor junctions during or after manufacture is possible. In this manner, one of the major causes of transistor failure is entirely precluded.

It is an object of the present invention to provide an improved semiconducting device having a protective coating thereover except for ohmic contact areas.

It is a still further object of the present invention to provide an improved transistor structure having a laterally extended base surface for ohmic contact thereto, and including covered junction and exposed transistor surfaces.

Various other possible objects and advantages of the present invention will become apparent to those skilled in the art from the following description of the present invention. Although the invention is herein illustrated with respect to particular preferred embodiments thereof, no limitation is intended thereby, and reference is made to the appended claims for a precise delineation of the true scope of the present invention.

The present invention is particularly well adapted to diode units as well as multi-element units. Although the problems encountered in high frequency triode transistors are normally more troublesome than those found in the diode art, yet the present invention provides material advantage diode semiconductors. Furthermore, although as previously noted, the present invention may be employed with a variety of semiconducting materials, yet actual use thereof has been primarily directed to silicon transistors and thus the following description is referenced thereto.

The invention is illustrated in the accompanying drawings wherein:

FIG. 1 is a plan view of a wafer of semiconducting material having the masking layer thereof removed within the illustrated circles;

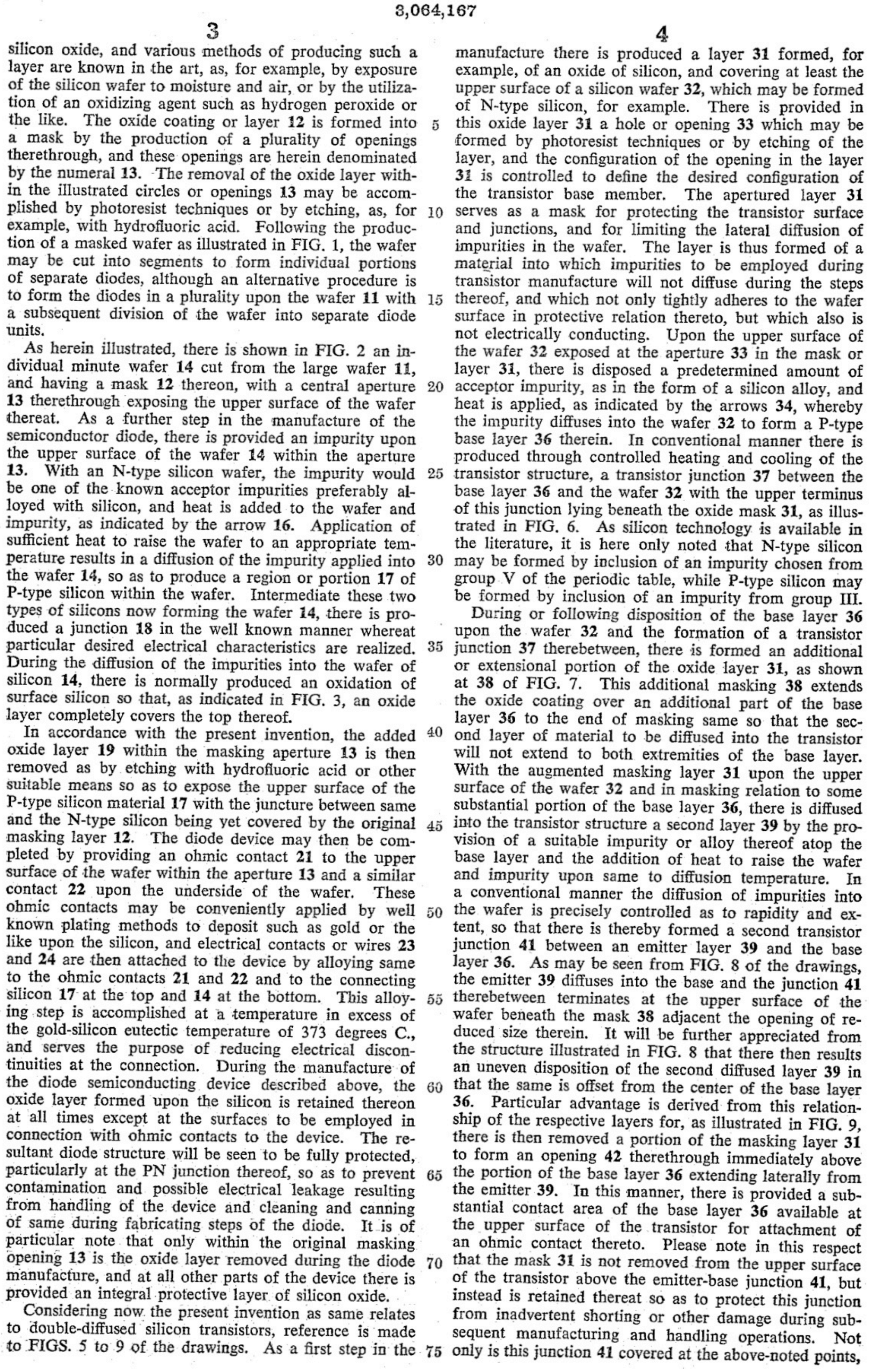
FIGS. 2, 3, and 4 are sectional views through a semiconducting diode device, at separate stages of manufacture thereof, in accordance with the present invention;

FIGS. 5, 6, 7, 8 and 9 are sectional views through a triode semiconducting device or transistor, showing same at separate stages of manufacture, in accordance with the present invention; and

FIG. 10 is a sectional view through a transistor in accordance with the present invention.

Reference is made to FIGS. 1 to 4, wherein there is illustrated a diode semiconducting device, at various stages of manufacture thereof, in accordance with the present invention. There is illustrated in FIG. 1 a wafer **11** formed of a semiconducting material such as silicon having, for example, an N-type impurity therein. This wafer **11** has formed thereon as a step of the present invention, a coating **12** entirely covering the upper surface of the wafer. Preferably, this coating is formed of a

Figure B.174: Jean Hoerni invented methods of manufacturing silicon transistors.



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silicon oxide, and various methods of producing such a layer are known in the art, as, for example, by exposure of the silicon wafer to moisture and air, or by the utilization of an oxidizing agent such as hydrogen peroxide or the like. The oxide coating or layer **12** is formed into a mask by the production of a plurality of openings therethrough, and these openings are herein denominated by the numeral **13**. The removal of the oxide layer within the illustrated circles or openings **13** may be accomplished by photoresist techniques or by etching, as, for example, with hydrofluoric acid. Following the production of a masked wafer as illustrated in FIG. 1, the wafer may be cut into segments to form individual portions of separate diodes, although an alternative procedure is to form the diodes in a plurality upon the wafer **11** with a subsequent division of the wafer into separate diode units.

As herein illustrated, there is shown in FIG. 2 an individual minute wafer **14** cut from the large wafer **11**, and having a mask **12** thereon, with a central aperture **13** therethrough exposing the upper surface of the wafer thereat. As a further step in the manufacture of the semiconductor diode, there is provided an impurity upon the upper surface of the wafer **14** within the aperture **13**. With an N-type silicon wafer, the impurity would be one of the known acceptor impurities preferably alloyed with silicon, and heat is added to the wafer and impurity, as indicated by the arrow **16**. Application of sufficient heat to raise the wafer to an appropriate temperature results in a diffusion of the impurity applied into the wafer **14**, so as to produce a region or portion **17** of P-type silicon within the wafer. Intermediate these two types of silicons now forming the wafer **14**, there is produced a junction **18** in the well known manner whereat particular desired electrical characteristics are realized. During the diffusion of the impurities into the wafer of silicon **14**, there is normally produced an oxidation of surface silicon so that, as indicated in FIG. 3, an oxide layer completely covers the top thereof.

In accordance with the present invention, the added oxide layer **19** within the masking aperture **13** is then removed as by etching with hydrofluoric acid or other suitable means so as to expose the upper surface of the P-type silicon material **17** with the juncture between same and the N-type silicon being yet covered by the original masking layer **12**. The diode device may then be completed by providing an ohmic contact **21** to the upper surface of the wafer within the aperture **13** and a similar contact **22** upon the underside of the wafer. These ohmic contacts may be conveniently applied by well known plating methods to deposit such as gold or the like upon the silicon, and electrical contacts or wires **23** and **24** are then attached to the device by alloying same to the ohmic contacts **21** and **22** and to the connecting silicon **17** at the top and **14** at the bottom. This alloying step is accomplished at a temperature in excess of the gold-silicon eutectic temperature of 373 degrees C., and serves the purpose of reducing electrical discontinuities at the connection. During the manufacture of the diode semiconducting device described above, the oxide layer formed upon the silicon is retained thereon at all times except at the surfaces to be employed in connection with ohmic contacts to the device. The resultant diode structure will be seen to be fully protected, particularly at the PN junction thereof, so as to prevent contamination and possible electrical leakage resulting from handling of the device and cleaning and canning of same during fabricating steps of the diode. It is of particular note that only within the original masking opening **13** is the oxide layer removed during the diode manufacture, and at all other parts of the device there is provided an integral protective layer of silicon oxide.

Considering now the present invention as same relates to double-diffused silicon transistors, reference is made to FIGS. 5 to 9 of the drawings. As a first step in the

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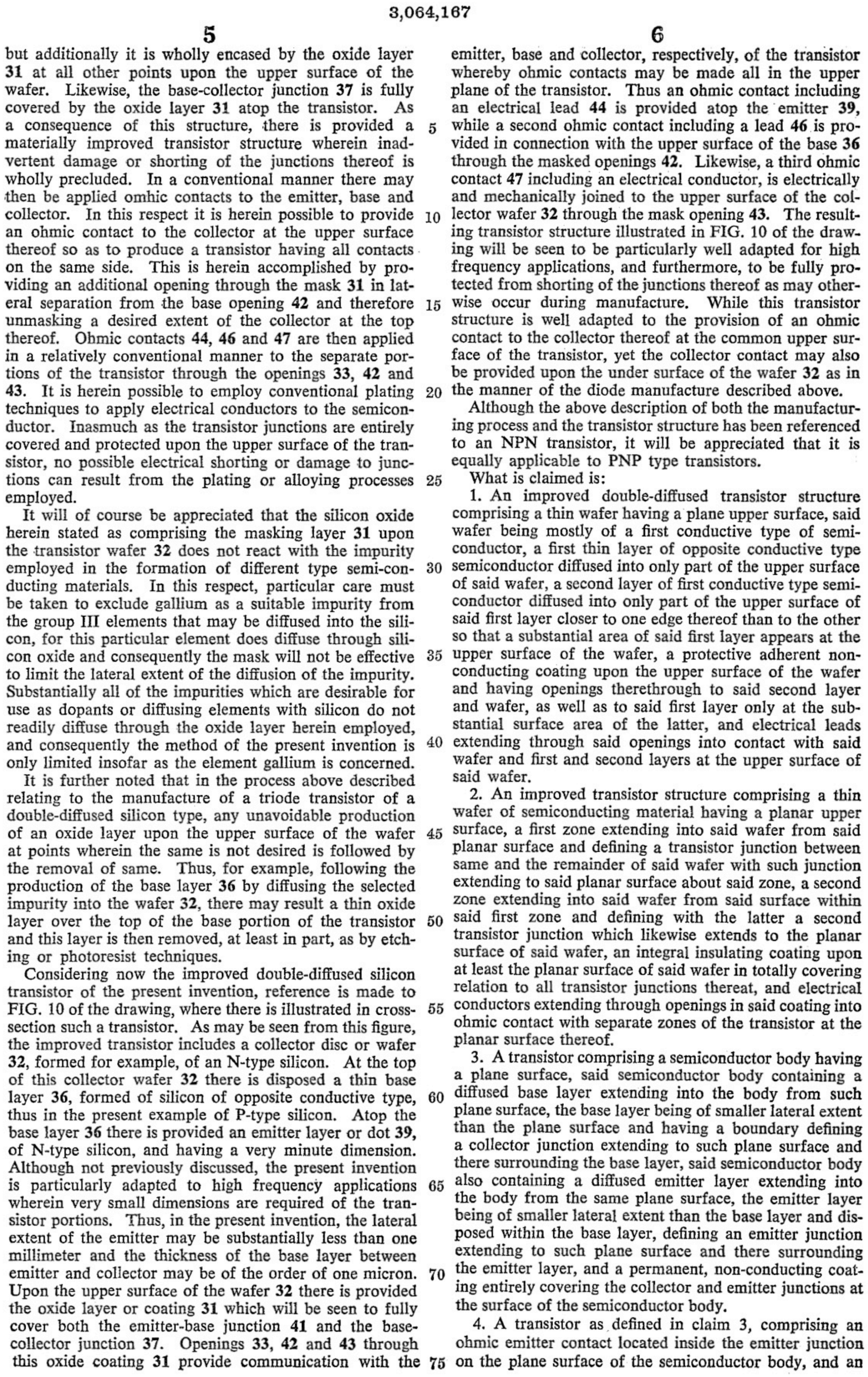
manufacture there is produced a layer **31** formed, for example, of an oxide of silicon, and covering at least the upper surface of a silicon wafer **32**, which may be formed of N-type silicon, for example. There is provided in this oxide layer **31** a hole or opening **33** which may be formed by photoresist techniques or by etching of the layer, and the configuration of the opening in the layer **31** is controlled to define the desired configuration of the transistor base member. The apertured layer **31** serves as a mask for protecting the transistor surface and junctions, and for limiting the lateral diffusion of impurities in the wafer. The layer is thus formed of a material into which impurities to be employed during transistor manufacture will not diffuse during the steps thereof, and which not only tightly adheres to the wafer surface in protective relation thereto, but which also is not electrically conducting. Upon the upper surface of the wafer **32** exposed at the aperture **33** in the mask or layer **31**, there is disposed a predetermined amount of acceptor impurity, as in the form of a silicon alloy, and heat is applied, as indicated by the arrows **34**, whereby the impurity diffuses into the wafer **32** to form a P-type base layer **36** therein. In conventional manner there is produced through controlled heating and cooling of the transistor structure, a transistor junction **37** between the base layer **36** and the wafer **32** with the upper terminus of this junction lying beneath the oxide mask **31**, as illustrated in FIG. 6. As silicon technology is available in the literature, it is here only noted that N-type silicon may be formed by inclusion of an impurity chosen from group V of the periodic table, while P-type silicon may be formed by inclusion of an impurity from group III.

During or following disposition of the base layer **36** upon the wafer **32** and the formation of a transistor junction **37** therebetween, there is formed an additional or extensional portion of the oxide layer **31**, as shown at **38** of FIG. 7. This additional masking **38** extends the oxide coating over an additional part of the base layer **36** to the end of masking same so that the second layer of material to be diffused into the transistor will not extend to both extremities of the base layer. With the augmented masking layer **31** upon the upper surface of the wafer **32** and in masking relation to some substantial portion of the base layer **36**, there is diffused into the transistor structure a second layer **39** by the provision of a suitable impurity or alloy thereof atop the base layer and the addition of heat to raise the wafer and impurity upon same to diffusion temperature. In a conventional manner the diffusion of impurities into the wafer is precisely controlled as to rapidity and extent, so that there is thereby formed a second transistor junction **41** between an emitter layer **39** and the base layer **36**. As may be seen from FIG. 8 of the drawings, the emitter **39** diffuses into the base and the junction **41** therebetween terminates at the upper surface of the wafer beneath the mask **38** adjacent the opening of reduced size therein. It will be further appreciated from the structure illustrated in FIG. 8 that there then results an uneven disposition of the second diffused layer **39** in that the same is offset from the center of the base layer **36**. Particular advantage is derived from this relationship of the respective layers for, as illustrated in FIG. 9, there is then removed a portion of the masking layer **31** to form an opening **42** therethrough immediately above the portion of the base layer **36** extending laterally from the emitter **39**. In this manner, there is provided a substantial contact area of the base layer **36** available at the upper surface of the transistor for attachment of an ohmic contact thereto. Please note in this respect that the mask **31** is not removed from the upper surface of the transistor above the emitter-base junction **41**, but instead is retained thereat so as to protect this junction from inadvertent shorting or other damage during subsequent manufacturing and handling operations. Not only is this junction **41** covered at the above-noted points,

Figure B.175: Jean Hoerni invented methods of manufacturing silicon transistors.



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but additionally it is wholly encased by the oxide layer **31** at all other points upon the upper surface of the wafer. Likewise, the base-collector junction **37** is fully covered by the oxide layer **31** atop the transistor. As a consequence of this structure, there is provided a materially improved transistor structure wherein inadvertent damage or shorting of the junctions thereof is wholly precluded. In a conventional manner there may then be applied omhic contacts to the emitter, base and collector. In this respect it is herein possible to provide an ohmic contact to the collector at the upper surface thereof so as to produce a transistor having all contacts on the same side. This is herein accomplished by providing an additional opening through the mask **31** in lateral separation from the base opening **42** and therefore unmasking a desired extent of the collector at the top thereof. Ohmic contacts **44**, **46** and **47** are then applied in a relatively conventional manner to the separate portions of the transistor through the openings **33**, **42** and **43**. It is herein possible to employ conventional plating techniques to apply electrical conductors to the semiconductor. Inasmuch as the transistor junctions are entirely covered and protected upon the upper surface of the transistor, no possible electrical shorting or damage to junctions can result from the plating or alloying processes employed.

It will of course be appreciated that the silicon oxide herein stated as comprising the masking layer **31** upon the transistor wafer **32** does not react with the impurity employed in the formation of different type semi-conducting materials. In this respect, particular care must be taken to exclude gallium as a suitable impurity from the group III elements that may be diffused into the silicon, for this particular element does diffuse through silicon oxide and consequently the mask will not be effective to limit the lateral extent of the diffusion of the impurity. Substantially all of the impurities which are desirable for use as dopants or diffusing elements with silicon do not readily diffuse through the oxide layer herein employed, and consequently the method of the present invention is only limited insofar as the element gallium is concerned.

It is further noted that in the process above described relating to the manufacture of a triode transistor of a double-diffused silicon type, any unavoidable production of an oxide layer upon the upper surface of the wafer at points wherein the same is not desired is followed by the removal of same. Thus, for example, following the production of the base layer **36** by diffusing the selected impurity into the wafer **32**, there may result a thin oxide layer over the top of the base portion of the transistor and this layer is then removed, at least in part, as by etching or photoresist techniques.

Considering now the improved double-diffused silicon transistor of the present invention, reference is made to FIG. 10 of the drawing, where there is illustrated in cross-section such a transistor. As may be seen from this figure, the improved transistor includes a collector disc or wafer **32**, formed for example, of an N-type silicon. At the top of this collector wafer **32** there is disposed a thin base layer **36**, formed of silicon of opposite conductive type, thus in the present example of P-type silicon. Atop the base layer **36** there is provided an emitter layer or dot **39**, of N-type silicon, and having a very minute dimension. Although not previously discussed, the present invention is particularly adapted to high frequency applications wherein very small dimensions are required of the transistor portions. Thus, in the present invention, the lateral extent of the emitter may be substantially less than one millimeter and the thickness of the base layer between emitter and collector may be of the order of one micron. Upon the upper surface of the wafer **32** there is provided the oxide layer or coating **31** which will be seen to fully cover both the emitter-base junction **41** and the base-collector junction **37**. Openings **33**, **42** and **43** through this oxide coating **31** provide communication with the

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emitter, base and collector, respectively, of the transistor whereby ohmic contacts may be made all in the upper plane of the transistor. Thus an ohmic contact including an electrical lead **44** is provided atop the emitter **39**, while a second ohmic contact including a lead **46** is provided in connection with the upper surface of the base **36** through the masked openings **42**. Likewise, a third ohmic contact **47** including an electrical conductor, is electrically and mechanically joined to the upper surface of the collector wafer **32** through the mask opening **43**. The resulting transistor structure illustrated in FIG. 10 of the drawing will be seen to be particularly well adapted for high frequency applications, and furthermore, to be fully protected from shorting of the junctions thereof as may otherwise occur during manufacture. While this transistor structure is well adapted to the provision of an ohmic contact to the collector thereof at the common upper surface of the transistor, yet the collector contact may also be provided upon the under surface of the wafer **32** as in the manner of the diode manufacture described above.

Although the above description of both the manufacturing process and the transistor structure has been referenced to an NPN transistor, it will be appreciated that it is equally applicable to PNP type transistors.

What is claimed is:

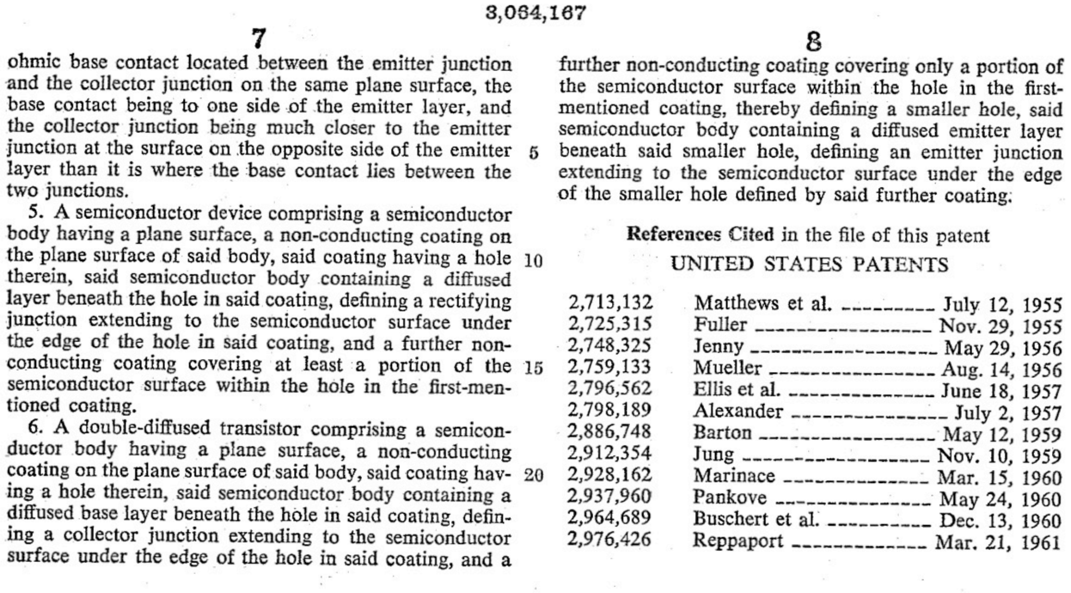
1. An improved double-diffused transistor structure comprising a thin wafer having a plane upper surface, said wafer being mostly of a first conductive type of semiconductor, a first thin layer of opposite conductive type semiconductor diffused into only part of the upper surface of said wafer, a second layer of first conductive type semiconductor diffused into only part of the upper surface of said first layer closer to one edge thereof than to the other so that a substantial area of said first layer appears at the upper surface of the wafer, a protective adherent non-conducting coating upon the upper surface of the wafer and having openings therethrough to said second layer and wafer, as well as to said first layer only at the substantial surface area of the latter, and electrical leads extending through said openings into contact with said wafer and first and second layers at the upper surface of said wafer.

2. An improved transistor structure comprising a thin wafer of semiconducting material having a planar upper surface, a first zone extending into said wafer from said planar surface and defining a transistor junction between same and the remainder of said wafer with such junction extending to said planar surface about said zone, a second zone extending into said wafer from said surface within said first zone and defining with the latter a second transistor junction which likewise extends to the planar surface of said wafer, an integral insulating coating upon at least the planar surface of said wafer in totally covering relation to all transistor junctions thereat, and electrical conductors extending through openings in said coating into ohmic contact with separate zones of the transistor at the planar surface thereof.

3. A transistor comprising a semiconductor body having a plane surface, said semiconductor body containing a diffused base layer extending into the body from such plane surface, the base layer being of smaller lateral extent than the plane surface and having a boundary defining a collector junction extending to such plane surface and there surrounding the base layer, said semiconductor body also containing a diffused emitter layer extending into the body from the same plane surface, the emitter layer being of smaller lateral extent than the base layer and disposed within the base layer, defining an emitter junction extending to such plane surface and there surrounding the emitter layer, and a permanent, non-conducting coating entirely covering the collector and emitter junctions at the surface of the semiconductor body.

4. A transistor as defined in claim 3, comprising an ohmic emitter contact located inside the emitter junction on the plane surface of the semiconductor body, and an

Figure B.176: Jean Hoerni invented methods of manufacturing silicon transistors.



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ohmic base contact located between the emitter junction and the collector junction on the same plane surface, the base contact being to one side of the emitter layer, and the collector junction being much closer to the emitter junction at the surface on the opposite side of the emitter layer than it is where the base contact lies between the two junctions.

5. A semiconductor device comprising a semiconductor body having a plane surface, a non-conducting coating on the plane surface of said body, said coating having a hole therein, said semiconductor body containing a diffused layer beneath the hole in said coating, defining a rectifying junction extending to the semiconductor surface under the edge of the hole in said coating, and a further non-conducting coating covering at least a portion of the semiconductor surface within the hole in the first-mentioned coating.

6. A double-diffused transistor comprising a semiconductor body having a plane surface, a non-conducting coating on the plane surface of said body, said coating having a hole therein, said semiconductor body containing a diffused base layer beneath the hole in said coating, defining a collector junction extending to the semiconductor surface under the edge of the hole in said coating, and a

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further non-conducting coating covering only a portion of the semiconductor surface within the hole in the first-mentioned coating, thereby defining a smaller hole, said semiconductor body containing a diffused emitter layer beneath said smaller hole, defining an emitter junction extending to the semiconductor surface under the edge of the smaller hole defined by said further coating.

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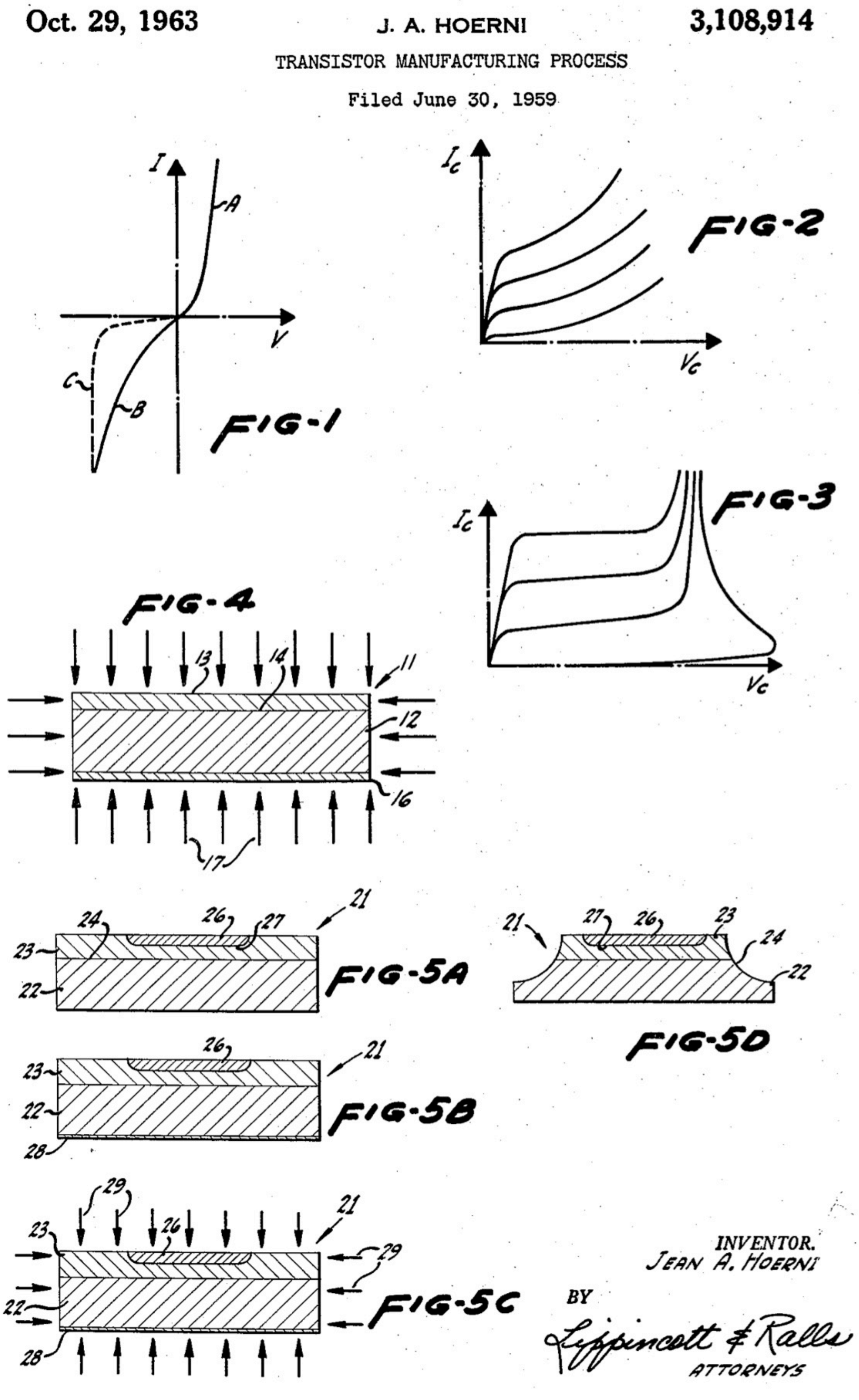
Figure B.177: Jean Hoerni invented methods of manufacturing silicon transistors.



Oct. 29, 1963 J. A. HOERNI **3,108,914**

TRANSISTOR MANUFACTURING PROCESS

Filed June 30, 1959

INVENTOR.
JEAN A. HOERNI

BY

Lippincott & Ralls
ATTORNEYS

Figure B.178: Jean Hoerni invented methods of manufacturing silicon transistors.

United States Patent Office

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Patented Oct. 29, 1963

3,108,914

TRANSISTOR MANUFACTURING PROCESS

Jean A. Hoerni, Los Altos, Calif., assignor, by mesne assignments, to Fairchild Camera and Instrument Corporation, Syosset, N.Y., a corporation of Delaware
Filed June 30, 1959, Ser. No. 823,954
8 Claims. (Cl. 148—186)

The present invention relates in general to the provision of a manufacturing process for semiconducting devices and more particularly to a process for improving the electrical characteristics of diode semiconductors and transistors to the end of establishing therein more sharply varying current-voltage characteristics.

The process of this invention contemplates the addition of a few simple steps in the manufacture or fabrication of semiconducting devices such as diodes and transistors, and includes the controlled addition to the semiconducting material of a selected metal impurity. Although it is common practice in the transistor art to controllably add impurities to the basic material, such as germanium or silicon, these impurities are normally designed to fulfill more obvious functions. In particular, it is conventional to diffuse selected impurities into silicon, for example, in order to produce transistor junctions within the material and a great body of art has arisen covering the manners and means for accomplishing the controlled addition of such impurities. It is also known that certain impurities may be added in controlled quantities to increase the lifetime of transistor carriers. Research in this latter field has indicated that nickel is highly desirable as an additive to improve the carrier lifetime, while certain other metals such as gold are highly undesirable in this respect. While great effort has been expended in certain aspects of the problems involved in controlling semiconductor characteristics by the addition of impurities with marked advancements resulting therefrom, certain other aspects of the problem have not been so treated. Thus, while it is possible to postulate the possible and desirable current-voltage relationship of a diode semiconductor, for example, it has been found that actual diodes tend to materially deviate therefrom, at least in certain aspects.

As regards diode semiconductors, it has been found that reverse breakdown voltage-current relationships tend not to vary sharply, as is desired for switching applications of these devices. To the contrary, many diodes exhibit gradually varying reverse breakdown characteristics and such diodes have been denominated as "soft diodes." This departure of actually manufactured diode structures from the desired characteristics thereof is quite substantial and often serves to materially limit applicability of the devices. For example, the reverse current flow at a particular value of reverse voltage for a commercially available semiconducting diode has been measured at 20 milliamperes as contrasted to a desired and expected current amplitude of 0.001 microamperes. It will be seen that the actual diode falls short of the theoretically predicted diode characteristics by a very large factor. The process of the present invention is directed to the production of diode semiconductors having the desired predicted reverse current-voltage relationships.

In the manufacture of transistors of three and more elements it has been likewise found that the variation of current with the voltage often assumes a relatively "soft" characteristic, wherein a gradual current variation with increased voltage results rather than an abrupt change, as may be desired. Specifically, as regards transistors, the collector current is often found to increase in a gradual and relatively uniform relationship with increased collector voltage, rather than the sharp current

increase desired at a particular value of collector voltage. The present invention is directed to the production of transistors having sharply varying electrical characteristics of the type more nearly following the predictable and desired current-voltage characteristics.

Although the above-noted characteristics of "soft diodes" and the similar characteristics of transistors have been recognized by many workers in the field, the difficulties of solid state analysis have to date effectively limited desired improvements therein. Theoretical approaches to solid state physics have proven quite difficult and, furthermore, complete and satisfactory analysis of solid state devices is also sufficiently difficult to seriously hamper full and complete understanding of the true causes of observed phenomenon. It has been postuated that certain undesirable electrical characteristics of semiconducting devices may be caused by the presence of particular impurities in the semiconducting material, or that such characteristics may be in part due to certain crystal lattice structures or imperfections. Various evidence is available to support different theories in this respect, however, it is well known that conventional manufacturing techniques produce many semiconducting devices which have certain of the electrical characteristics thereof wholly unsuited to particular applications of the device, while at the same time certain other semiconducting devices produced by the same or like process may have the desired electrical characteristics.

Although it is not herein intended to postulate a new theory of solid state physics which is basically adapted to provide theoretical solutions to presently existing problems, there is herein provided a manufacturing process which provides a highly desirable improvement in transistor characteristics. The process hereof actually relates to an addition to normal and conventional transistor manufacturing processes. Only very simple and inexpensive operations are required to carry out the process of this invention, and the same are readily adapted for inclusion in conventional transistor manufacturing methods. In accordance herewith there is controllably diffused into the semiconducting material of a device such as a transistor, a limited amount of a particular metal which serves to materially vary the electrical characteristics of the material so processed. In distinction to previous impurity diffusion processes, the materials herein suited for diffusion include the so-called "deep level impurities," such being defined in the literature. Gold and nickel are embraced by the foregoing definition. While it is true that nickel has been previously employed for diffusion into semiconducting materials for reasons wholly different from the present invention, it is widely accepted that the diffusion of gold into semiconducting material is highly deleterious, inasmuch as gold impurities tend to materially reduce the carrier lifetime. Various other of the deep level impurities are likewise generally considered to be unacceptable as impurities in even minute amounts in semiconducting material because of various deleterious effects attributable thereto.

It is an object of the present invention to provide an improved process of manufacturing semiconducting devices.

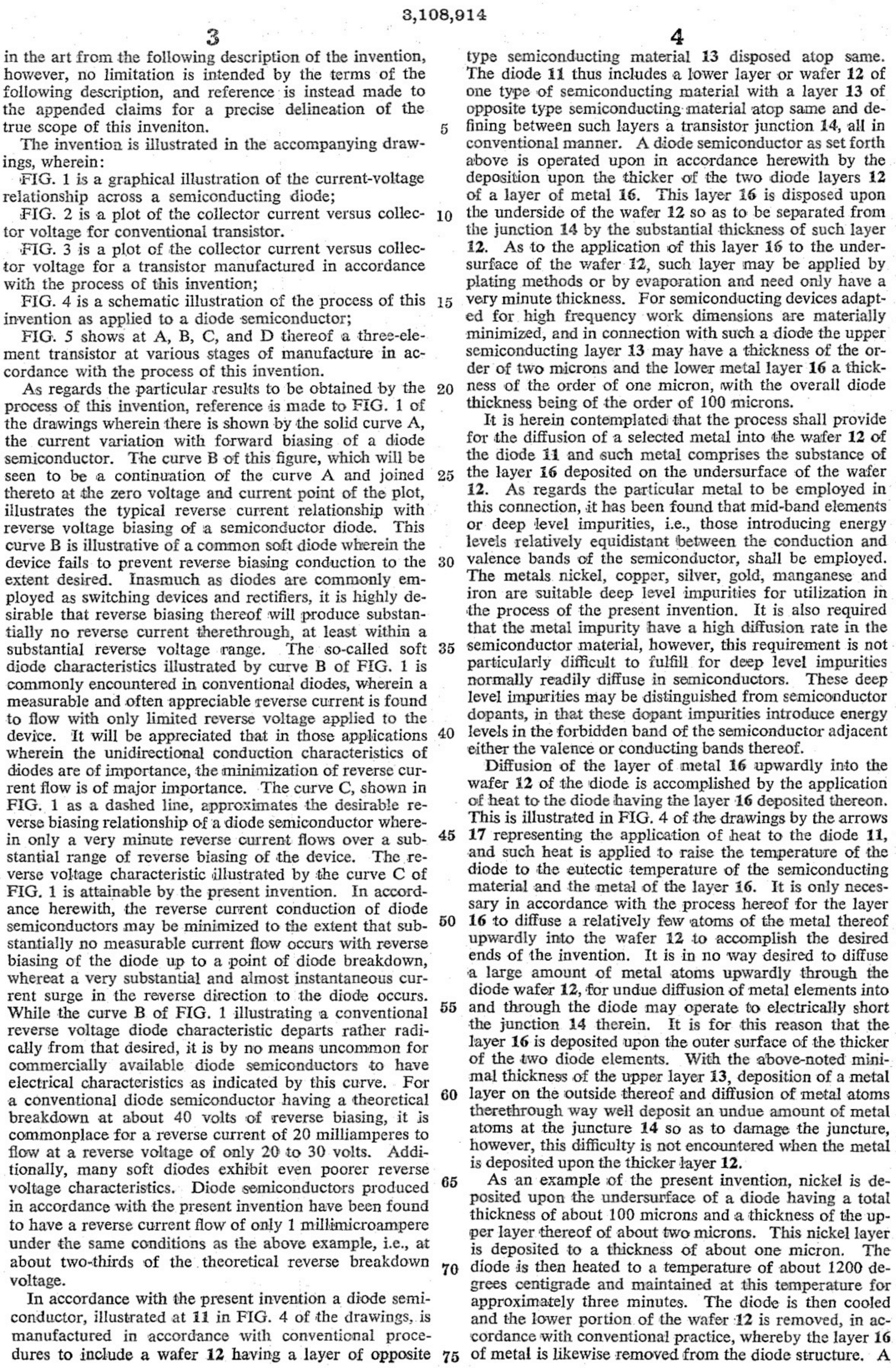
It is another object of the present invention to provide a process for improving the electrical characteristics of semiconducting devices.

It is a further object of the present invention to provide a process for improving the electrical characteristics of transistors to sharpen the current-voltage relationship.

It is yet another object of the present invention to provide an improvement process for establishing sharp characteristics of otherwise soft semiconductor diodes.

Various other objects and possible advantages of the present invention will become apparent to those skilled

Figure B.179: Jean Hoerni invented methods of manufacturing silicon transistors.



in the art from the following description of the invention, however, no limitation is intended by the terms of the following description, and reference is instead made to the appended claims for a precise delineation of the true scope of this inveniton.

The invention is illustrated in the accompanying drawings, wherein:

FIG. 1 is a graphical illustration of the current-voltage relationship across a semiconducting diode;

FIG. 2 is a plot of the collector current versus collector voltage for conventional transistor.

FIG. 3 is a plot of the collector current versus collector voltage for a transistor manufactured in accordance with the process of this invention;

FIG. 4 is a schematic illustration of the process of this invention as applied to a diode semiconductor;

FIG. 5 shows at A, B, C, and D thereof a three-element transistor at various stages of manufacture in accordance with the process of this invention.

As regards the particular results to be obtained by the process of this invention, reference is made to FIG. 1 of the drawings wherein there is shown by the solid curve A, the current variation with forward biasing of a diode semiconductor. The curve B of this figure, which will be seen to be a continuation of the curve A and joined thereto at the zero voltage and current point of the plot, illustrates the typical reverse current relationship with reverse voltage biasing of a semiconductor diode. This curve B is illustrative of a common soft diode wherein the device fails to prevent reverse biasing conduction to the extent desired. Inasmuch as diodes are commonly employed as switching devices and rectifiers, it is highly desirable that reverse biasing thereof will produce substantially no reverse current therethrough, at least within a substantial reverse voltage range. The so-called soft diode characteristics illustrated by curve B of FIG. 1 is commonly encountered in conventional diodes, wherein a measurable and often appreciable reverse current is found to flow with only limited reverse voltage applied to the device. It will be appreciated that in those applications wherein the unidirectional conduction characteristics of diodes are of importance, the minimization of reverse current flow is of major importance. The curve C, shown in FIG. 1 as a dashed line, approximates the desirable reverse biasing relationship of a diode semiconductor wherein only a very minute reverse current flows over a substantial range of reverse biasing of the device. The reverse voltage characteristic illustrated by the curve C of FIG. 1 is attainable by the present invention. In accordance herewith, the reverse current conduction of diode semiconductors may be minimized to the extent that substantially no measurable current flow occurs with reverse biasing of the diode up to a point of diode breakdown, whereat a very substantial and almost instantaneous current surge in the reverse direction to the diode occurs. While the curve B of FIG. 1 illustrating a conventional reverse voltage diode characteristic departs rather radically from that desired, it is by no means uncommon for commercially available diode semiconductors to have electrical characteristics as indicated by this curve. For a conventional diode semiconductor having a theoretical breakdown at about 40 volts of reverse biasing, it is commonplace for a reverse current of 20 milliamperes to flow at a reverse voltage of only 20 to 30 volts. Additionally, many soft diodes exhibit even poorer reverse voltage characteristics. Diode semiconductors produced in accordance with the present invention have been found to have a reverse current flow of only 1 millimicroampere under the same conditions as the above example, i.e., at about two-thirds of the theoretical reverse breakdown voltage.

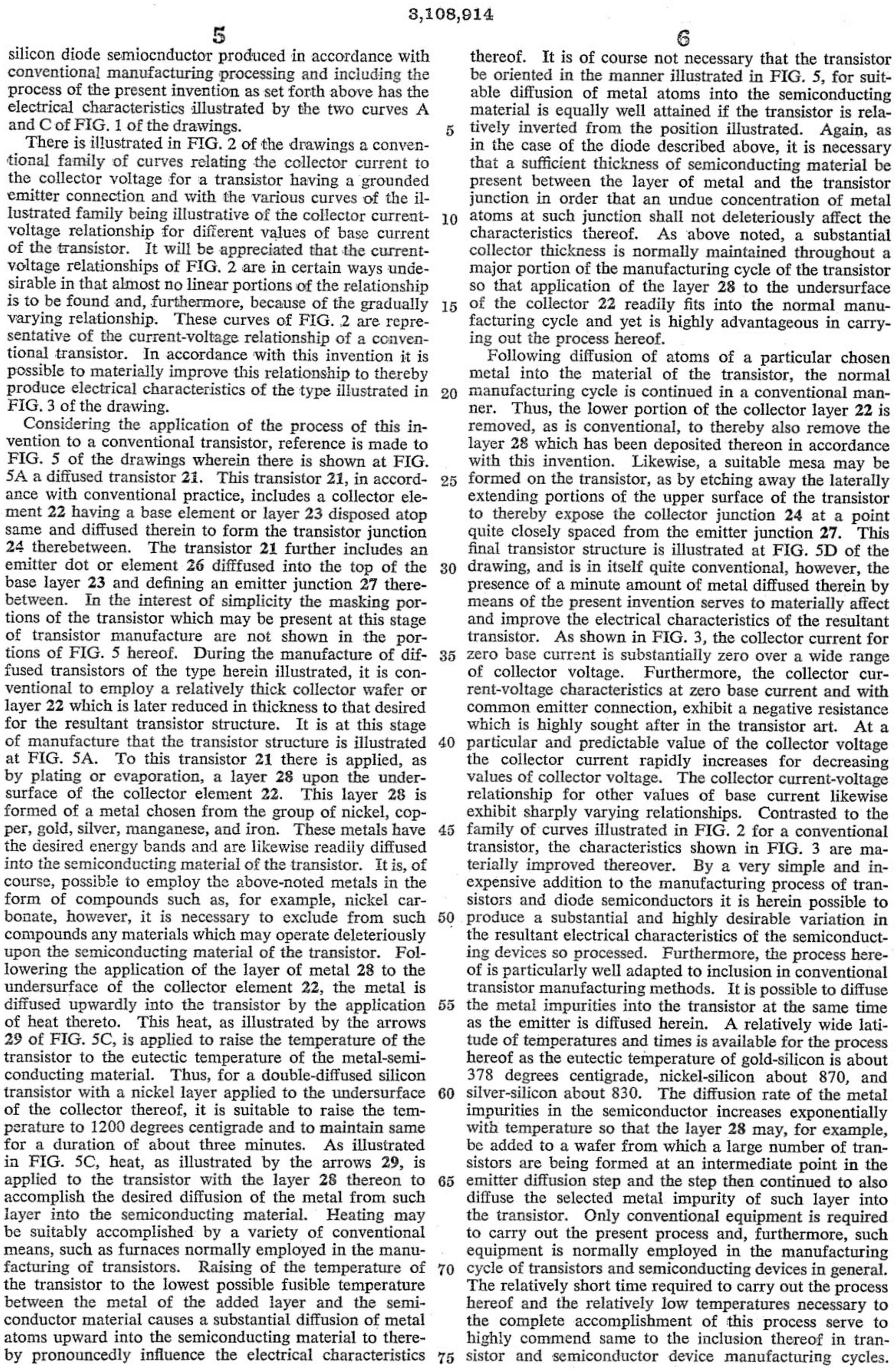
In accordance with the present invention a diode semiconductor, illustrated at **11** in FIG. 4 of the drawings, is manufactured in accordance with conventional procedures to include a wafer **12** having a layer of opposite type semiconducting material **13** disposed atop same. The diode **11** thus includes a lower layer or wafer **12** of one type of semiconducting material with a layer **13** of opposite type semiconducting material atop same and defining between such layers a transistor junction **14**, all in conventional manner. A diode semiconductor as set forth above is operated upon in accordance herewith by the deposition upon the thicker of the two diode layers **12** of a layer of metal **16**. This layer **16** is disposed upon the underside of the wafer **12** so as to be separated from the junction **14** by the substantial thickness of such layer **12**. As to the application of this layer **16** to the undersurface of the wafer **12**, such layer may be applied by plating methods or by evaporation and need only have a very minute thickness. For semiconducting devices adapted for high frequency work dimensions are materially minimized, and in connection with such a diode the upper semiconducting layer **13** may have a thickness of the order of two microns and the lower metal layer **16** a thickness of the order of one micron, with the overall diode thickness being of the order of 100 microns.

It is herein contemplated that the process shall provide for the diffusion of a selected metal into the wafer **12** of the diode **11** and such metal comprises the substance of the layer **16** deposited on the undersurface of the wafer **12**. As regards the particular metal to be employed in this connection, it has been found that mid-band elements or deep level impurities, i.e., those introducing energy levels relatively equidistant between the conduction and valence bands of the semiconductor, shall be employed. The metals nickel, copper, silver, gold, manganese and iron are suitable deep level impurities for utilization in the process of the present invention. It is also required that the metal impurity have a high diffusion rate in the semiconductor material, however, this requirement is not particularly difficult to fulfill for deep level impurities normally readily diffuse in semiconductors. These deep level impurities may be distinguished from semiconductor dopants, in that these dopant impurities introduce energy levels in the forbidden band of the semiconductor adjacent either the valence or conducting bands thereof.

Diffusion of the layer of metal **16** upwardly into the wafer **12** of the diode is accomplished by the application of heat to the diode having the layer **16** deposited thereon. This is illustrated in FIG. 4 of the drawings by the arrows **17** representing the application of heat to the diode **11**, and such heat is applied to raise the temperature of the diode to the eutectic temperature of the semiconducting material and the metal of the layer **16**. It is only necessary in accordance with the process hereof for the layer **16** to diffuse a relatively few atoms of the metal thereof upwardly into the wafer **12** to accomplish the desired ends of the invention. It is in no way desired to diffuse a large amount of metal atoms upwardly through the diode wafer **12**, for undue diffusion of metal elements into and through the diode may operate to electrically short the junction **14** therein. It is for this reason that the layer **16** is deposited upon the outer surface of the thicker of the two diode elements. With the above-noted minimal thickness of the upper layer **13**, deposition of a metal layer on the outside thereof and diffusion of metal atoms therethrough way well deposit an undue amount of metal atoms at the juncture **14** so as to damage the juncture, however, this difficulty is not encountered when the metal is deposited upon the thicker layer **12**.

As an example of the present invention, nickel is deposited upon the undersurface of a diode having a total thickness of about 100 microns and a thickness of the upper layer thereof of about two microns. This nickel layer is deposited to a thickness of about one micron. The diode is then heated to a temperature of about 1200 degrees centigrade and maintained at this temperature for approximately three minutes. The diode is then cooled and the lower portion of the wafer **12** is removed, in accordance with conventional practice, whereby the layer **16** of metal is likewise removed from the diode structure. A

Figure B.180: Jean Hoerni invented methods of manufacturing silicon transistors.



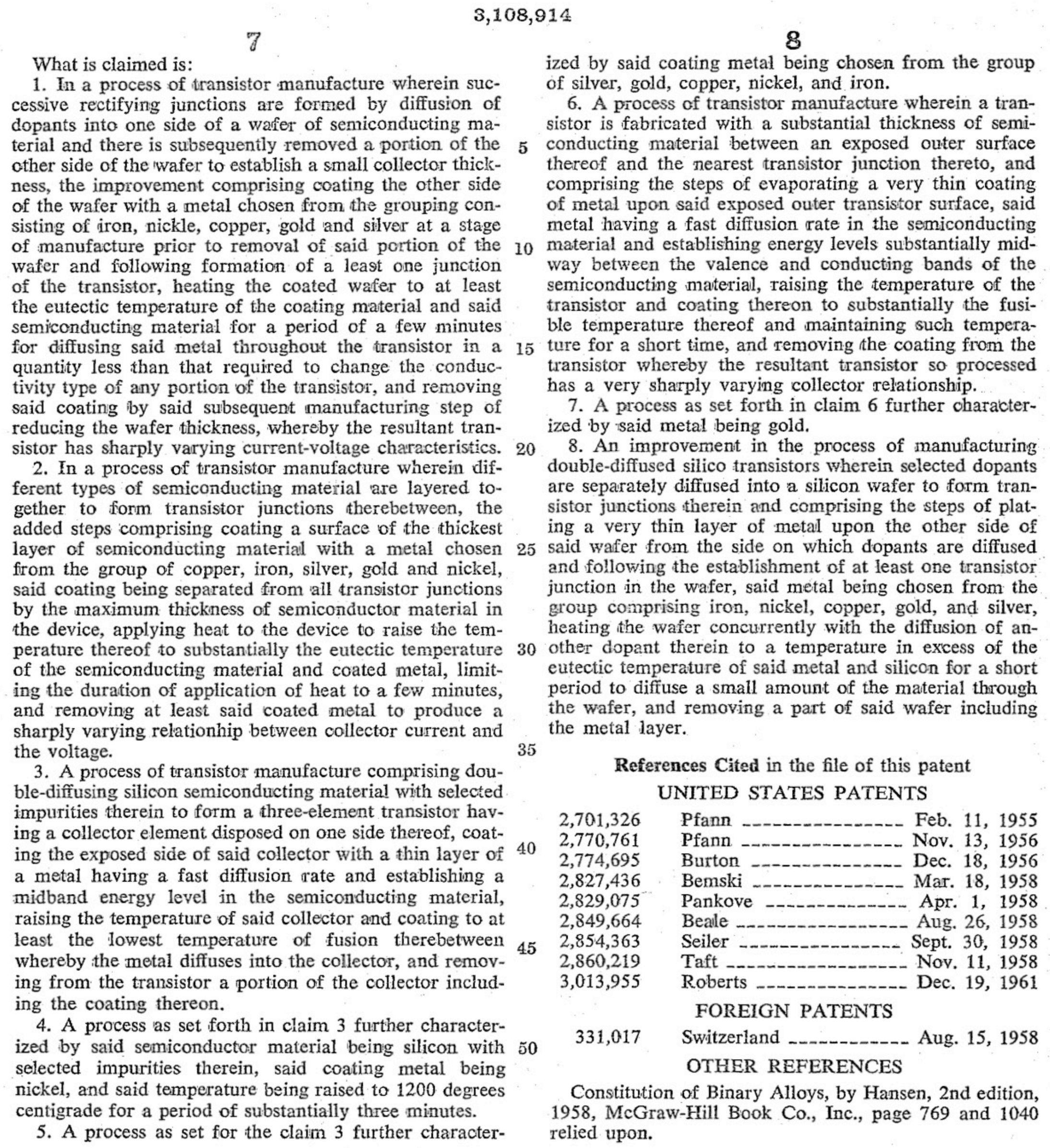
silicon diode semiocnductor produced in accordance with conventional manufacturing processing and including the process of the present invention as set forth above has the electrical characteristics illustrated by the two curves A and C of FIG. 1 of the drawings.

There is illustrated in FIG. 2 of the drawings a conventional family of curves relating the collector current to the collector voltage for a transistor having a grounded emitter connection and with the various curves of the illustrated family being illustrative of the collector current-voltage relationship for different values of base current of the transistor. It will be appreciated that the current-voltage relationships of FIG. 2 are in certain ways undesirable in that almost no linear portions of the relationship is to be found and, furthermore, because of the gradually varying relationship. These curves of FIG. 2 are representative of the current-voltage relationship of a conventional transistor. In accordance with this invention it is possible to materially improve this relationship to thereby produce electrical characteristics of the type illustrated in FIG. 3 of the drawing.

Considering the application of the process of this invention to a conventional transistor, reference is made to FIG. 5 of the drawings wherein there is shown at FIG. 5A a diffused transistor **21**. This transistor **21**, in accordance with conventional practice, includes a collector element **22** having a base element or layer **23** disposed atop same and diffused therein to form the transistor junction **24** therebetween. The transistor **21** further includes an emitter dot or element **26** difffused into the top of the base layer **23** and defining an emitter junction **27** therebetween. In the interest of simplicity the masking portions of the transistor which may be present at this stage of transistor manufacture are not shown in the portions of FIG. 5 hereof. During the manufacture of diffused transistors of the type herein illustrated, it is conventional to employ a relatively thick collector wafer or layer **22** which is later reduced in thickness to that desired for the resultant transistor structure. It is at this stage of manufacture that the transistor structure is illustrated at FIG. 5A. To this transistor **21** there is applied, as by plating or evaporation, a layer **28** upon the undersurface of the collector element **22**. This layer **28** is formed of a metal chosen from the group of nickel, copper, gold, silver, manganese, and iron. These metals have the desired energy bands and are likewise readily diffused into the semiconducting material of the transistor. It is, of course, possible to employ the above-noted metals in the form of compounds such as, for example, nickel carbonate, however, it is necessary to exclude from such compounds any materials which may operate deleteriously upon the semiconducting material of the transistor. Followering the application of the layer of metal **28** to the undersurface of the collector element **22**, the metal is diffused upwardly into the transistor by the application of heat thereto. This heat, as illustrated by the arrows **29** of FIG. 5C, is applied to raise the temperature of the transistor to the eutectic temperature of the metal-semiconducting material. Thus, for a double-diffused silicon transistor with a nickel layer applied to the undersurface of the collector thereof, it is suitable to raise the temperature to 1200 degrees centigrade and to maintain same for a duration of about three minutes. As illustrated in FIG. 5C, heat, as illustrated by the arrows **29**, is applied to the transistor with the layer **28** thereon to accomplish the desired diffusion of the metal from such layer into the semiconducting material. Heating may be suitably accomplished by a variety of conventional means, such as furnaces normally employed in the manufacturing of transistors. Raising of the temperature of the transistor to the lowest possible fusible temperature between the metal of the added layer and the semiconductor material causes a substantial diffusion of metal atoms upward into the semiconducting material to thereby pronouncedly influence the electrical characteristics thereof. It is of course not necessary that the transistor be oriented in the manner illustrated in FIG. 5, for suitable diffusion of metal atoms into the semiconducting material is equally well attained if the transistor is relatively inverted from the position illustrated. Again, as in the case of the diode described above, it is necessary that a sufficient thickness of semiconducting material be present between the layer of metal and the transistor junction in order that an undue concentration of metal atoms at such junction shall not deleteriously affect the characteristics thereof. As above noted, a substantial collector thickness is normally maintained throughout a major portion of the manufacturing cycle of the transistor so that application of the layer **28** to the undersurface of the collector **22** readily fits into the normal manufacturing cycle and yet is highly advantageous in carrying out the process hereof.

Following diffusion of atoms of a particular chosen metal into the material of the transistor, the normal manufacturing cycle is continued in a conventional manner. Thus, the lower portion of the collector layer **22** is removed, as is conventional, to thereby also remove the layer **28** which has been deposited thereon in accordance with this invention. Likewise, a suitable mesa may be formed on the transistor, as by etching away the laterally extending portions of the upper surface of the transistor to thereby expose the collector junction **24** at a point quite closely spaced from the emitter junction **27**. This final transistor structure is illustrated at FIG. 5D of the drawing, and is in itself quite conventional, however, the presence of a minute amount of metal diffused therein by means of the present invention serves to materially affect and improve the electrical characteristics of the resultant transistor. As shown in FIG. 3, the collector current for zero base current is substantially zero over a wide range of collector voltage. Furthermore, the collector current-voltage characteristics at zero base current and with common emitter connection, exhibit a negative resistance which is highly sought after in the transistor art. At a particular and predictable value of the collector voltage the collector current rapidly increases for decreasing values of collector voltage. The collector current-voltage relationship for other values of base current likewise exhibit sharply varying relationships. Contrasted to the family of curves illustrated in FIG. 2 for a conventional transistor, the characteristics shown in FIG. 3 are materially improved thereover. By a very simple and inexpensive addition to the manufacturing process of transistors and diode semiconductors it is herein possible to produce a substantial and highly desirable variation in the resultant electrical characteristics of the semiconducting devices so processed. Furthermore, the process hereof is particularly well adapted to inclusion in conventional transistor manufacturing methods. It is possible to diffuse the metal impurities into the transistor at the same time as the emitter is diffused herein. A relatively wide latitude of temperatures and times is available for the process hereof as the eutectic temperature of gold-silicon is about 378 degrees centigrade, nickel-silicon about 870, and silver-silicon about 830. The diffusion rate of the metal impurities in the semiconductor increases exponentially with temperature so that the layer **28** may, for example, be added to a wafer from which a large number of transistors are being formed at an intermediate point in the emitter diffusion step and the step then continued to also diffuse the selected metal impurity of such layer into the transistor. Only conventional equipment is required to carry out the present process and, furthermore, such equipment is normally employed in the manufacturing cycle of transistors and semiconducting devices in general. The relatively short time required to carry out the process hereof and the relatively low temperatures necessary to the complete accomplishment of this process serve to highly commend same to the inclusion thereof in transistor and semiconductor device manufacturing cycles.

Figure B.181: Jean Hoerni invented methods of manufacturing silicon transistors.



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What is claimed is:

1. In a process of transistor manufacture wherein successive rectifying junctions are formed by diffusion of dopants into one side of a wafer of semiconducting material and there is subsequently removed a portion of the other side of the wafer to establish a small collector thickness, the improvement comprising coating the other side of the wafer with a metal chosen from the grouping consisting of iron, nickle, copper, gold and silver at a stage of manufacture prior to removal of said portion of the wafer and following formation of a least one junction of the transistor, heating the coated wafer to at least the eutectic temperature of the coating material and said semiconducting material for a period of a few minutes for diffusing said metal throughout the transistor in a quantity less than that required to change the conductivity type of any portion of the transistor, and removing said coating by said subsequent manufacturing step of reducing the wafer thickness, whereby the resultant transistor has sharply varying current-voltage characteristics.

2. In a process of transistor manufacture wherein different types of semiconducting material are layered together to form transistor junctions therebetween, the added steps comprising coating a surface of the thickest layer of semiconducting material with a metal chosen from the group of copper, iron, silver, gold and nickel, said coating being separated from all transistor junctions by the maximum thickness of semiconductor material in the device, applying heat to the device to raise the temperature thereof to substantially the eutectic temperature of the semiconducting material and coated metal, limiting the duration of application of heat to a few minutes, and removing at least said coated metal to produce a sharply varying relationhip between collector current and the voltage.

3. A process of transistor manufacture comprising double-diffusing silicon semiconducting material with selected impurities therein to form a three-element transistor having a collector element disposed on one side thereof, coating the exposed side of said collector with a thin layer of a metal having a fast diffusion rate and establishing a midband energy level in the semiconducting material, raising the temperature of said collector and coating to at least the lowest temperature of fusion therebetween whereby the metal diffuses into the collector, and removing from the transistor a portion of the collector including the coating thereon.

4. A process as set forth in claim 3 further characterized by said semiconductor material being silicon with selected impurities therein, said coating metal being nickel, and said temperature being raised to 1200 degrees centigrade for a period of substantially three minutes.

5. A process as set for the claim 3 further characterized by said coating metal being chosen from the group of silver, gold, copper, nickel, and iron.

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6. A process of transistor manufacture wherein a transistor is fabricated with a substantial thickness of semiconducting material between an exposed outer surface thereof and the nearest transistor junction thereto, and comprising the steps of evaporating a very thin coating of metal upon said exposed outer transistor surface, said metal having a fast diffusion rate in the semiconducting material and establishing energy levels substantially midway between the valence and conducting bands of the semiconducting material, raising the temperature of the transistor and coating thereon to substantially the fusible temperature thereof and maintaining such temperature for a short time, and removing the coating from the transistor whereby the resultant transistor so processed has a very sharply varying collector relationship.

7. A process as set forth in claim 6 further characterized by said metal being gold.

8. An improvement in the process of manufacturing double-diffused silico transistors wherein selected dopants are separately diffused into a silicon wafer to form transistor junctions therein and comprising the steps of plating a very thin layer of metal upon the other side of said wafer from the side on which dopants are diffused and following the establishment of at least one transistor junction in the wafer, said metal being chosen from the group comprising iron, nickel, copper, gold, and silver, heating the wafer concurrently with the diffusion of another dopant therein to a temperature in excess of the eutectic temperature of said metal and silicon for a short period to diffuse a small amount of the material through the wafer, and removing a part of said wafer including the metal layer.

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Figure B.182: Jean Hoerni invented methods of manufacturing silicon transistors.

Nov. 19, 1968 F. P. HEIMAN ET AL 3,411,199

SEMICONDUCTOR DEVICE FABRICATION

Filed May 23, 1965 3 Sheets-Sheet 1

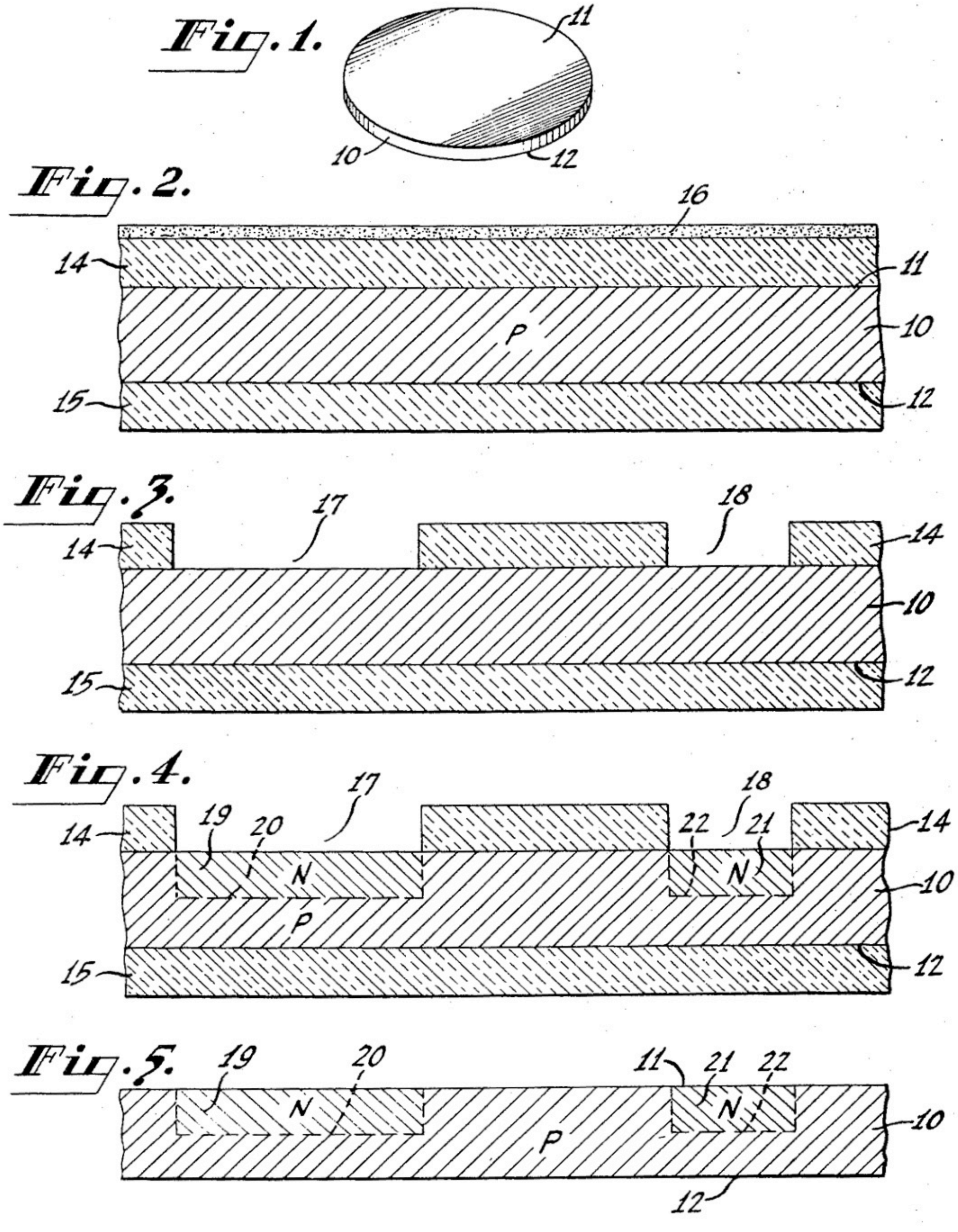

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Figure B.183: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.

Nov. 19, 1968 F. P. HEIMAN ET AL **3,411,199**

SEMICONDUCTOR DEVICE FABRICATION

Filed May 28, 1965 3 Sheets-Sheet 2

Fig. 6.

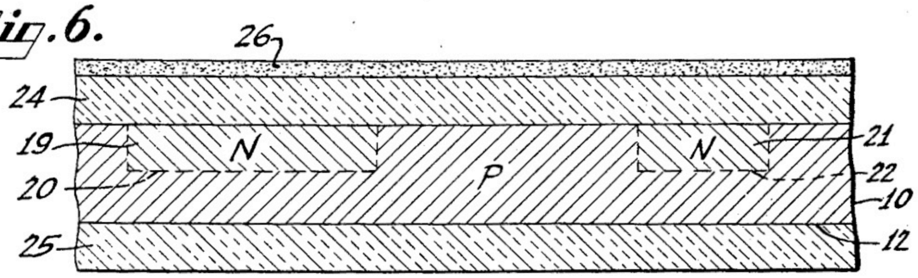

Fig. 7.

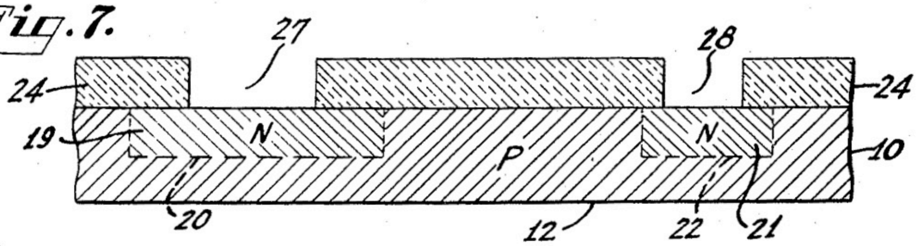

Fig. 8.

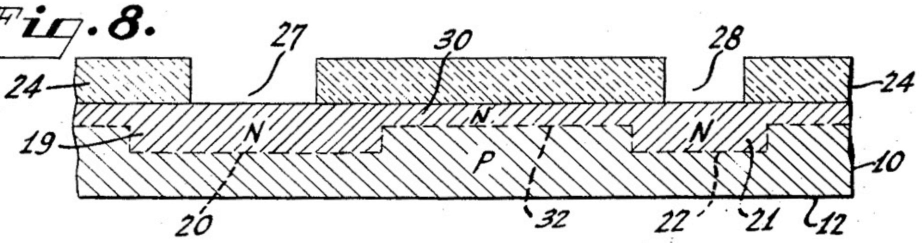

Fig. 9.

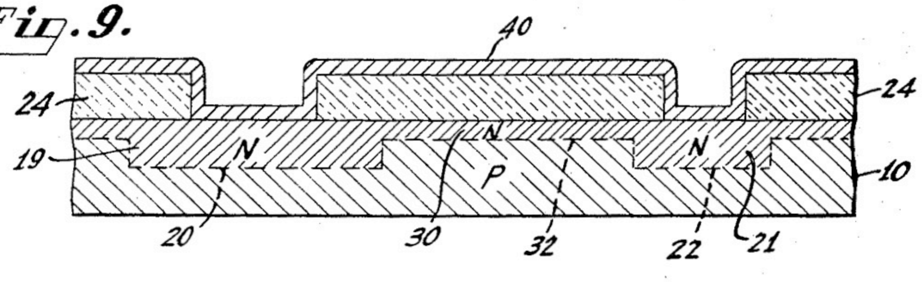

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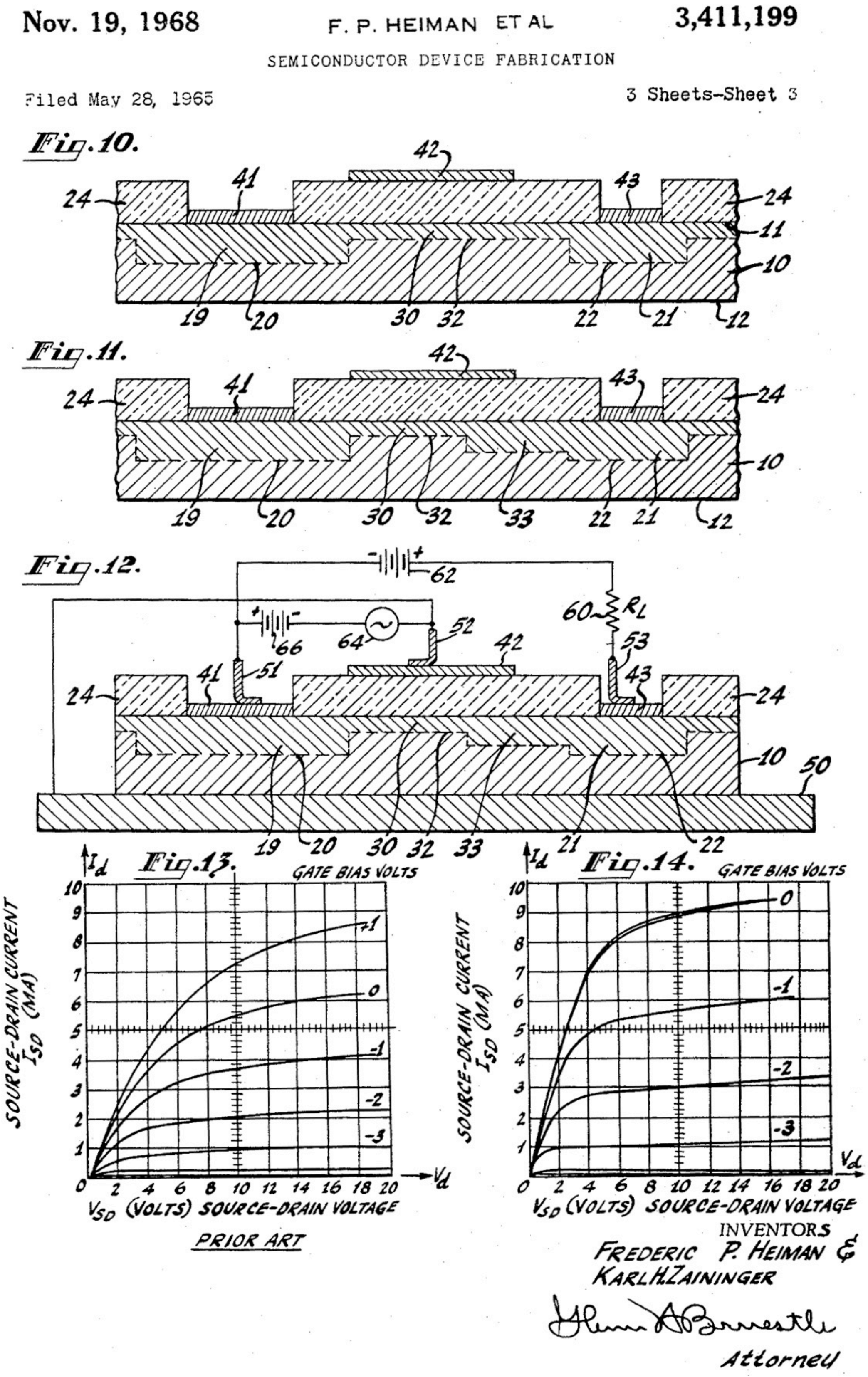
Figure B.184: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



Nov. 19, 1968 F. P. HEIMAN ET AL 3,411,199

SEMICONDUCTOR DEVICE FABRICATION

Filed May 28, 1965 3 Sheets-Sheet 3

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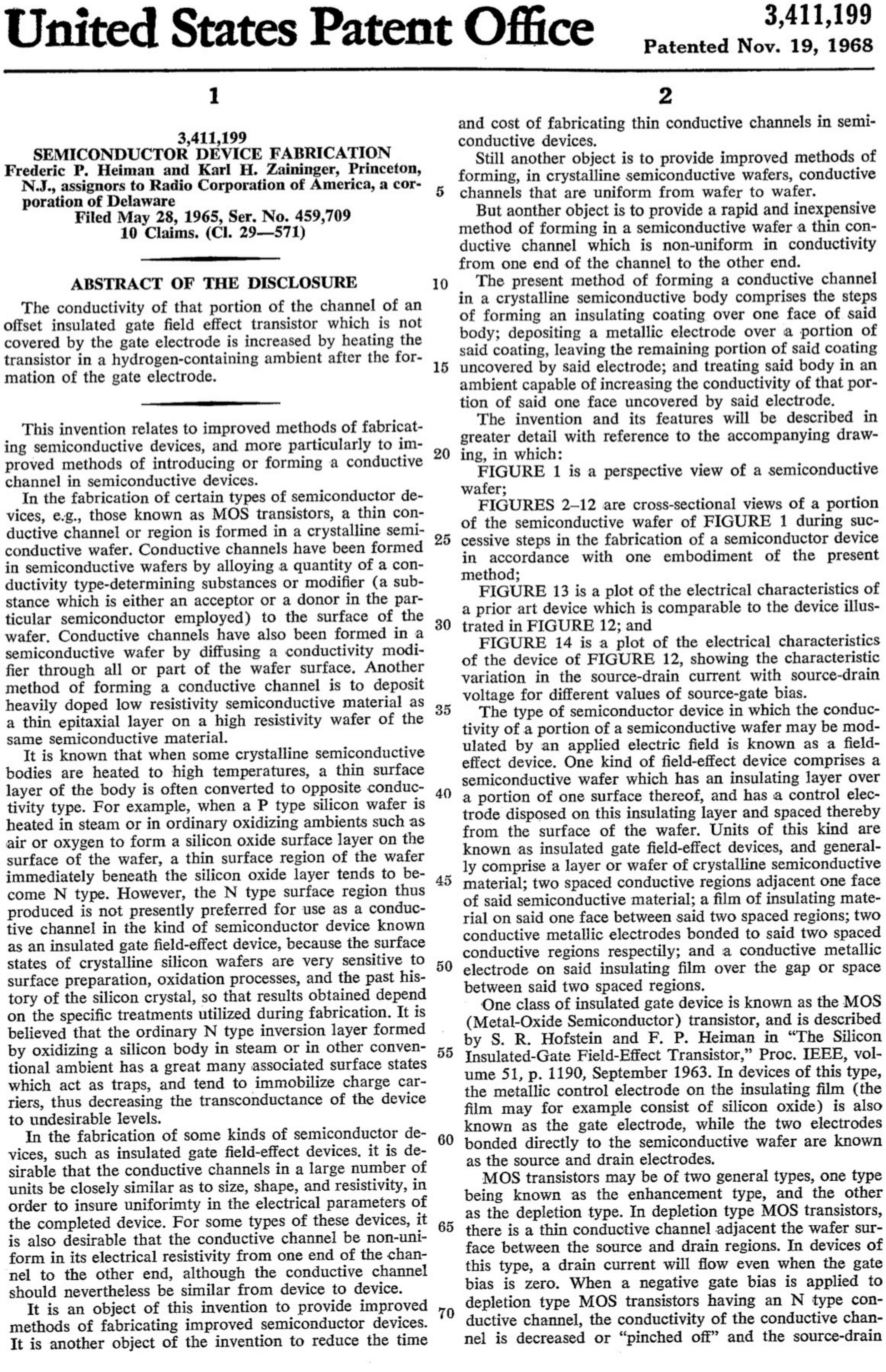
Figure B.185: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



United States Patent Office

3,411,199
Patented Nov. 19, 1968

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3,411,199
SEMICONDUCTOR DEVICE FABRICATION
Frederic P. Heiman and Karl H. Zaininger, Princeton, N.J., assignors to Radio Corporation of America, a corporation of Delaware
Filed May 28, 1965, Ser. No. 459,709
10 Claims. (Cl. 29—571)

ABSTRACT OF THE DISCLOSURE

The conductivity of that portion of the channel of an offset insulated gate field effect transistor which is not covered by the gate electrode is increased by heating the transistor in a hydrogen-containing ambient after the formation of the gate electrode.

This invention relates to improved methods of fabricating semiconductive devices, and more particularly to improved methods of introducing or forming a conductive channel in semiconductive devices.

In the fabrication of certain types of semiconductor devices, e.g., those known as MOS transistors, a thin conductive channel or region is formed in a crystalline semiconductive wafer. Conductive channels have been formed in semiconductive wafers by alloying a quantity of a conductivity type-determining substances or modifier (a substance which is either an acceptor or a donor in the particular semiconductor employed) to the surface of the wafer. Conductive channels have also been formed in a semiconductive wafer by diffusing a conductivity modifier through all or part of the wafer surface. Another method of forming a conductive channel is to deposit heavily doped low resistivity semiconductive material as a thin epitaxial layer on a high resistivity wafer of the same semiconductive material.

It is known that when some crystalline semiconductive bodies are heated to high temperatures, a thin surface layer of the body is often converted to opposite conductivity type. For example, when a P type silicon wafer is heated in steam or in ordinary oxidizing ambients such as air or oxygen to form a silicon oxide surface layer on the surface of the wafer, a thin surface region of the wafer immediately beneath the silicon oxide layer tends to become N type. However, the N type surface region thus produced is not presently preferred for use as a conductive channel in the kind of semiconductor device known as an insulated gate field-effect device, because the surface states of crystalline silicon wafers are very sensitive to surface preparation, oxidation processes, and the past history of the silicon crystal, so that results obtained depend on the specific treatments utilized during fabrication. It is believed that the ordinary N type inversion layer formed by oxidizing a silicon body in steam or in other conventional ambient has a great many associated surface states which act as traps, and tend to immobilize charge carriers, thus decreasing the transconductance of the device to undesirable levels.

In the fabrication of some kinds of semiconductor devices, such as insulated gate field-effect devices. it is desirable that the conductive channels in a large number of units be closely similar as to size, shape, and resistivity, in order to insure uniforimty in the electrical parameters of the completed device. For some types of these devices, it is also desirable that the conductive channel be non-uniform in its electrical resistivity from one end of the channel to the other end, although the conductive channel should nevertheless be similar from device to device.

It is an object of this invention to provide improved methods of fabricating improved semiconductor devices. It is another object of the invention to reduce the time

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and cost of fabricating thin conductive channels in semiconductive devices.

Still another object is to provide improved methods of forming, in crystalline semiconductive wafers, conductive channels that are uniform from wafer to wafer.

But aonther object is to provide a rapid and inexpensive method of forming in a semiconductive wafer a thin conductive channel which is non-uniform in conductivity from one end of the channel to the other end.

The present method of forming a conductive channel in a crystalline semiconductive body comprises the steps of forming an insulating coating over one face of said body; depositing a metallic electrode over a portion of said coating, leaving the remaining portion of said coating uncovered by said electrode; and treating said body in an ambient capable of increasing the conductivity of that portion of said one face uncovered by said electrode.

The invention and its features will be described in greater detail with reference to the accompanying drawing, in which:

FIGURE 1 is a perspective view of a semiconductive wafer;

FIGURES 2–12 are cross-sectional views of a portion of the semiconductive wafer of FIGURE 1 during successive steps in the fabrication of a semiconductor device in accordance with one embodiment of the present method;

FIGURE 13 is a plot of the electrical characteristics of a prior art device which is comparable to the device illustrated in FIGURE 12; and

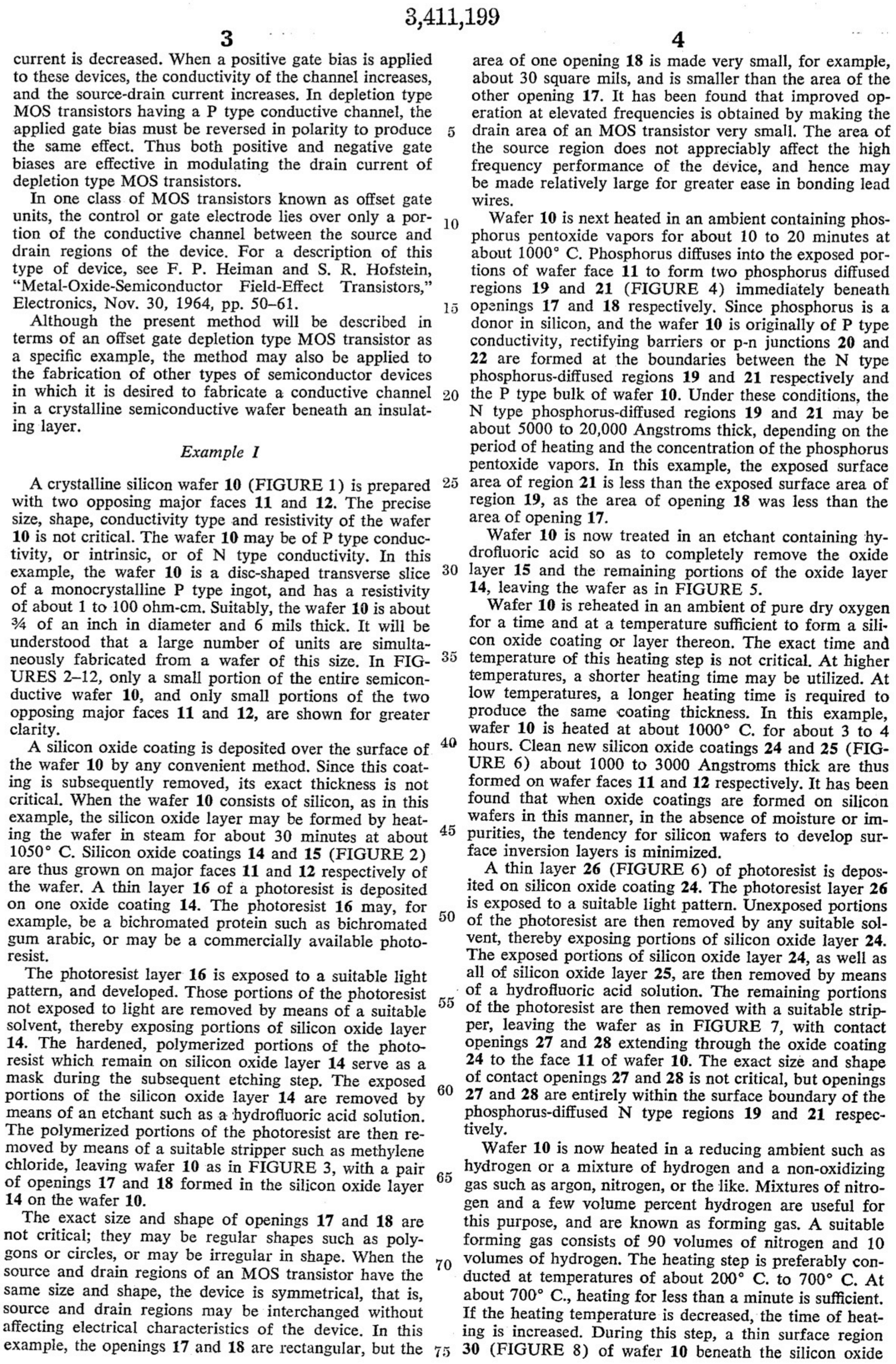
FIGURE 14 is a plot of the electrical characteristics of the device of FIGURE 12, showing the characteristic variation in the source-drain current with source-drain voltage for different values of source-gate bias.

The type of semiconductor device in which the conductivity of a portion of a semiconductive wafer may be modulated by an applied electric field is known as a field-effect device. One kind of field-effect device comprises a semiconductive wafer which has an insulating layer over a portion of one surface thereof, and has a control electrode disposed on this insulating layer and spaced thereby from the surface of the wafer. Units of this kind are known as insulated gate field-effect devices, and generally comprise a layer or wafer of crystalline semiconductive material; two spaced conductive regions adjacent one face of said semiconductive material; a film of insulating material on said one face between said two spaced regions; two conductive metallic electrodes bonded to said two spaced conductive regions respectily; and a conductive metallic electrode on said insulating film over the gap or space between said two spaced regions.

One class of insulated gate device is known as the MOS (Metal-Oxide Semiconductor) transistor, and is described by S. R. Hofstein and F. P. Heiman in "The Silicon Insulated-Gate Field-Effect Transistor," Proc. IEEE, volume 51, p. 1190, September 1963. In devices of this type, the metallic control electrode on the insulating film (the film may for example consist of silicon oxide) is also known as the gate electrode, while the two electrodes bonded directly to the semiconductive wafer are known as the source and drain electrodes.

MOS transistors may be of two general types, one type being known as the enhancement type, and the other as the depletion type. In depletion type MOS transistors, there is a thin conductive channel adjacent the wafer surface between the source and drain regions. In devices of this type, a drain current will flow even when the gate bias is zero. When a negative gate bias is applied to depletion type MOS transistors having an N type conductive channel, the conductivity of the conductive channel is decreased or "pinched off" and the source-drain

Figure B.186: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



current is decreased. When a positive gate bias is applied to these devices, the conductivity of the channel increases, and the source-drain current increases. In depletion type MOS transistors having a P type conductive channel, the applied gate bias must be reversed in polarity to produce the same effect. Thus both positive and negative gate biases are effective in modulating the drain current of depletion type MOS transistors.

In one class of MOS transistors known as offset gate units, the control or gate electrode lies over only a portion of the conductive channel between the source and drain regions of the device. For a description of this type of device, see F. P. Heiman and S. R. Hofstein, "Metal-Oxide-Semiconductor Field-Effect Transistors," Electronics, Nov. 30, 1964, pp. 50–61.

Although the present method will be described in terms of an offset gate depletion type MOS transistor as a specific example, the method may also be applied to the fabrication of other types of semiconductor devices in which it is desired to fabricate a conductive channel in a crystalline semiconductive wafer beneath an insulating layer.

Example I

A crystalline silicon wafer **10** (FIGURE 1) is prepared with two opposing major faces **11** and **12**. The precise size, shape, conductivity type and resistivity of the wafer **10** is not critical. The wafer **10** may be of P type conductivity, or intrinsic, or of N type conductivity. In this example, the wafer **10** is a disc-shaped transverse slice of a monocrystalline P type ingot, and has a resistivity of about 1 to 100 ohm-cm. Suitably, the wafer **10** is about ¾ of an inch in diameter and 6 mils thick. It will be understood that a large number of units are simultaneously fabricated from a wafer of this size. In FIGURES 2–12, only a small portion of the entire semiconductive wafer **10**, and only small portions of the two opposing major faces **11** and **12**, are shown for greater clarity.

A silicon oxide coating is deposited over the surface of the wafer **10** by any convenient method. Since this coating is subsequently removed, its exact thickness is not critical. When the wafer **10** consists of silicon, as in this example, the silicon oxide layer may be formed by heating the wafer in steam for about 30 minutes at about 1050° C. Silicon oxide coatings **14** and **15** (FIGURE 2) are thus grown on major faces **11** and **12** respectively of the wafer. A thin layer **16** of a photoresist is deposited on one oxide coating **14**. The photoresist **16** may, for example, be a bichromated protein such as bichromated gum arabic, or may be a commercially available photoresist.

The photoresist layer **16** is exposed to a suitable light pattern, and developed. Those portions of the photoresist not exposed to light are removed by means of a suitable solvent, thereby exposing portions of silicon oxide layer **14**. The hardened, polymerized portions of the photoresist which remain on silicon oxide layer **14** serve as a mask during the subsequent etching step. The exposed portions of the silicon oxide layer **14** are removed by means of an etchant such as a hydrofluoric acid solution. The polymerized portions of the photoresist are then removed by means of a suitable stripper such as methylene chloride, leaving wafer **10** as in FIGURE 3, with a pair of openings **17** and **18** formed in the silicon oxide layer **14** on the wafer **10**.

The exact size and shape of openings **17** and **18** are not critical; they may be regular shapes such as polygons or circles, or may be irregular in shape. When the source and drain regions of an MOS transistor have the same size and shape, the device is symmetrical, that is, source and drain regions may be interchanged without affecting electrical characteristics of the device. In this example, the openings **17** and **18** are rectangular, but the area of one opening **18** is made very small, for example, about 30 square mils, and is smaller than the area of the other opening **17**. It has been found that improved operation at elevated frequencies is obtained by making the drain area of an MOS transistor very small. The area of the source region does not appreciably affect the high frequency performance of the device, and hence may be made relatively large for greater ease in bonding lead wires.

Wafer **10** is next heated in an ambient containing phosphorus pentoxide vapors for about 10 to 20 minutes at about 1000° C. Phosphorus diffuses into the exposed portions of wafer face **11** to form two phosphorus diffused regions **19** and **21** (FIGURE 4) immediately beneath openings **17** and **18** respectively. Since phosphorus is a donor in silicon, and the wafer **10** is originally of P type conductivity, rectifying barriers or p-n junctions **20** and **22** are formed at the boundaries between the N type phosphorus-diffused regions **19** and **21** respectively and the P type bulk of wafer **10**. Under these conditions, the N type phosphorus-diffused regions **19** and **21** may be about 5000 to 20,000 Angstroms thick, depending on the period of heating and the concentration of the phosphorus pentoxide vapors. In this example, the exposed surface area of region **21** is less than the exposed surface area of region **19**, as the area of opening **18** was less than the area of opening **17**.

Wafer **10** is now treated in an etchant containing hydrofluoric acid so as to completely remove the oxide layer **15** and the remaining portions of the oxide layer **14**, leaving the wafer as in FIGURE 5.

Wafer **10** is reheated in an ambient of pure dry oxygen for a time and at a temperature sufficient to form a silicon oxide coating or layer thereon. The exact time and temperature of this heating step is not critical. At higher temperatures, a shorter heating time may be utilized. At low temperatures, a longer heating time is required to produce the same coating thickness. In this example, wafer **10** is heated at about 1000° C. for about 3 to 4 hours. Clean new silicon oxide coatings **24** and **25** (FIGURE 6) about 1000 to 3000 Angstroms thick are thus formed on wafer faces **11** and **12** respectively. It has been found that when oxide coatings are formed on silicon wafers in this manner, in the absence of moisture or impurities, the tendency for silicon wafers to develop surface inversion layers is minimized.

A thin layer **26** (FIGURE 6) of photoresist is deposited on silicon oxide coating **24**. The photoresist layer **26** is exposed to a suitable light pattern. Unexposed portions of the photoresist are then removed by any suitable solvent, thereby exposing portions of silicon oxide layer **24**. The exposed portions of silicon oxide layer **24**, as well as all of silicon oxide layer **25**, are then removed by means of a hydrofluoric acid solution. The remaining portions of the photoresist are then removed with a suitable stripper, leaving the wafer as in FIGURE 7, with contact openings **27** and **28** extending through the oxide coating **24** to the face **11** of wafer **10**. The exact size and shape of contact openings **27** and **28** is not critical, but openings **27** and **28** are entirely within the surface boundary of the phosphorus-diffused N type regions **19** and **21** respectively.

Wafer **10** is now heated in a reducing ambient such as hydrogen or a mixture of hydrogen and a non-oxidizing gas such as argon, nitrogen, or the like. Mixtures of nitrogen and a few volume percent hydrogen are useful for this purpose, and are known as forming gas. A suitable forming gas consists of 90 volumes of nitrogen and 10 volumes of hydrogen. The heating step is preferably conducted at temperatures of about 200° C. to 700° C. At about 700° C., heating for less than a minute is sufficient. If the heating temperature is decreased, the time of heating is increased. During this step, a thin surface region **30** (FIGURE 8) of wafer **10** beneath the silicon oxide

Figure B.187: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.

coating **24** is converted to N type conductivity. The thin surface region **30** is known as an inversion layer, and when formed in this manner is sufficiently trap-free to be utilized as a conductive channel. A p-n junction **32** is formed at the boundary between the inversion layer **30** and the bulk of wafer **10**.

The inversion layer **30** thus formed is too thin for accurate direct measurement. The thicknesses of the various wafer regions in the drawing are not to scale, and have been exaggerated for greated clarity. Layer **30** is estimated to be of the order of 100 Angstroms thick. Although the thickness of the conductive channel or inversion layer **30** is thus less than the length of a single wave of visible light, the presence of the conductive channel after this treatment may be demonstrated by placing two probes against the wafer surface on the two regions **19** and **21** respectively, and measuring with an ammeter the current which flows between the two probes for a given applied voltage. When such measurement is made on a wafer that does not have a conductive channel or surface region, the assemblage acts like a pair of diodes back-to-back, and very little current flows for a given applied voltage. When such measurement is made on a wafer that does have a conductive channel or surface region **30** between the regions **19** and **21**, a substantial current flows for a similar applied voltage. Suitably, the resistance of the channel **30** in this example is about 10 to 100 ohms.

The silicon body **10** is cooled to room temperature, and a film **40** (FIGURE 9) of a conductive metal is deposited by any convenient method over the remaining portion of oxide layer **24** and over the exposed portions of wafer face **11**. In this example, film **40** consists of chrome-gold or chrome-silver, is about 3000 to 6000 Angstroms thick, and is deposited by evaporation. A thin film of chromium is deposited first, and a layer of gold or silver is then deposited by vacuum evaporation on the chromium.

Desired portions of the chrome-gold film **40** on wafer regions **19** and **21** and on a portion of the oxide layer **24** between wafer regions **19** and **21** are now masked, utilizing either the photoresist techniques described above, or an acid resist (not shown) such as paraffin wax, apiezon wax, or the like. The unmasked portions of metal film **40** are removed by means of a suitable etchant, and the resist is dissolved by a suitable organic solvent, leaving a first portion of the metallic film as an electrode **41** (FIGURE 10) in contact with wafer region **19**; a second portion of the metallic film as an electrode **43** in contact with wafer region **21**; and a third portion as an electrode **42** on the silicon oxide coating **24**. Since the device of this example is an offset gate unit, the electrode **42** covers only part of the conducting channel **30**.

As a series drain resistance merely increases the drain voltage at which the drain current saturates, while a series source resistance introduces undesirable degeneration, it is preferred to offset the gate electrode so that one end of the gate electrode extends directly over the source region, and overlaps it slightly, while the other end of the gate electrode extends over part of the conductive channel, but does not extend across the entire gap between the source and drain regions. The feedback capacitance of the device is thus reduced, since the active channel length is forced to coincide with that portion of the gate electrode which lies over the channel.

The wafer **10** is now reheated in hydrogen, or in a hydrogen-containing ambient such as forming gas, for a few minutes at a temperature of about 200° C. to 700° C. As a result of this step, the hydrogen increases the conductivity of the uncovered portion only of channel **30**. The portion of channel **30** which is covered by the electrode **42** is not affected by this step, since the metal electrode **42** appears to act as a mask against the diffusion of hydrogen. It is preferred that the electrode **42** consists of dense alloys, or of dense metals such as gold and silver, which are capable of acting as a mask against the diffusion of hydrogen. In FIGURE 11, the uncovered portion of the conductive channel **32** which is given increased conductivity by this step has been legended **33**, and is shown, for greater clarity, as thicker than the remainder of channel **30**. It will be understood that portion **33** of the conductive channel differs from the remainder of original channel **30** principally in that portion **33** is more conductive than the remainder of channel **30**.

The device is completed (FIGURE 12) by bonding electrical lead wires **51**, **52** and **53** to electrodes **41**, **42** and **43** respectively by any convenient method such as soldering, or thermocompression bonding. Each portion **10′** may now be cut from the wafer to form a plurality of individual units. An individual portion **10′** of the wafer is mounted with major face **12** down on a metallic header **50**. The subsequent steps of encapsulating and encasing the device are accomplished by standard techniques of the semiconductor art, and need not be described here.

The device of this example may be operated as follows. Leads **51** and **53** are the source and drain leads respectively, while lead **52** is the control or gate lead. The load, shown as a resistance **60**, together with a source of direct current potential, such as a battery **62**, are connected in series between the source lead **51** and the drain lead **53**, so that the source eletcrode **41** and the source region **19** are poled negative relative to the drain electrode **42** and the drain region **21**. The header **50** is electrically connected to the gate lead **52**. A source **64** of signal potential and a second source of direct current potential, such as a battery **66**, are connected in series between the control lead **52** and the source lead **51** so that the source lead **51** is biased positive relative to the gate lead **52**.

The characteristic I–V curves of an offset gate MOS transistor fabricated according to this example are graphed in FIGURE 14. The graph is a plot of the source-drain current measured in milliamperes, against source-drain voltage, measured in volts, for different values of positive and negative gate-to-source bias, measured in volts. Depending on the times and temperatures of the process, the zero bias current may be increased or decreased. By increasing the period of treatment in a hydrogen-containing ambient, the conductivity of the channel in the device is increased, and hence the amount of current which flows at zero bias is increased.

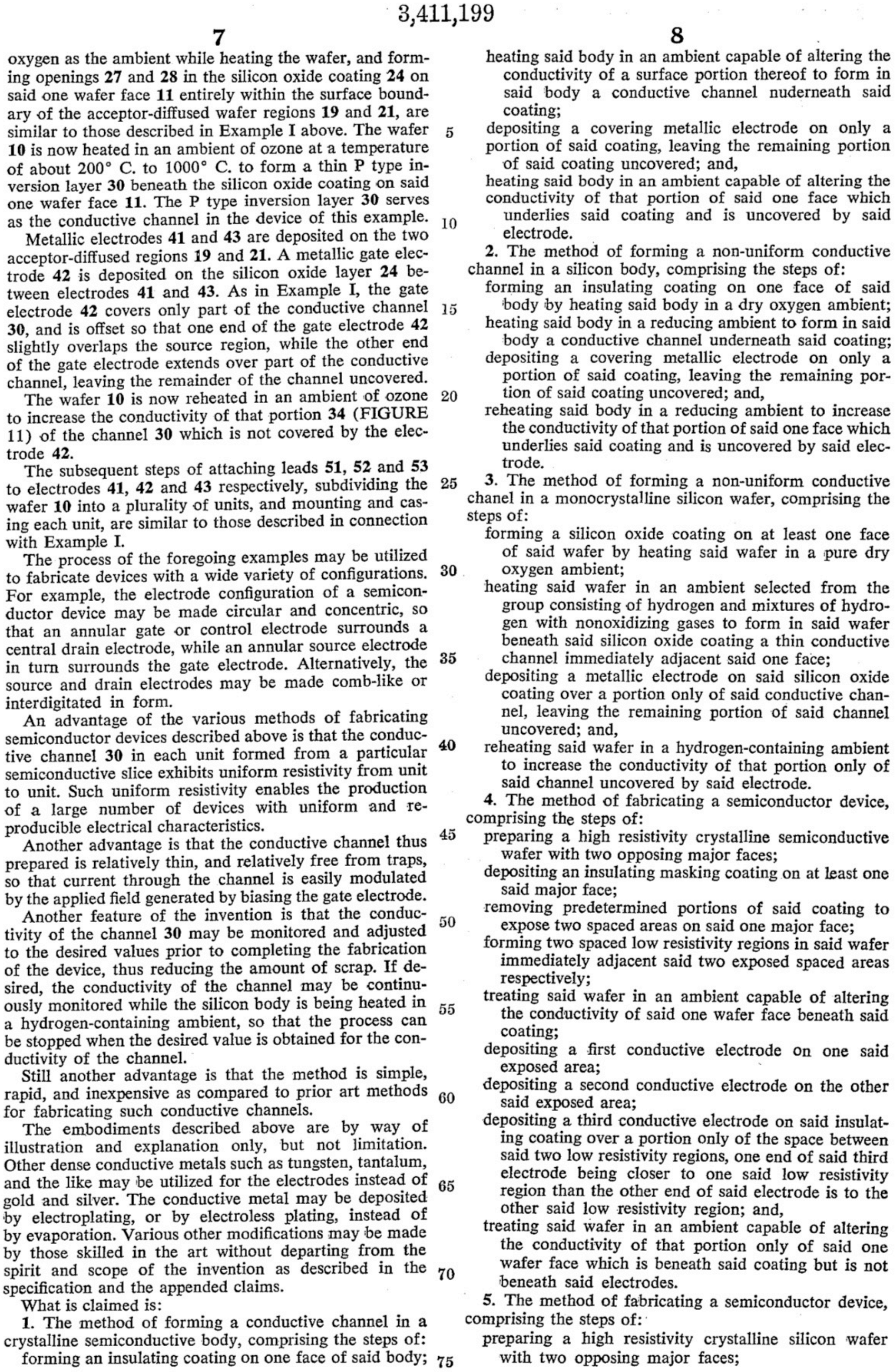
For comparison, FIGURE 13 shows the characteristic I–V curves of a comparable prior art device. In the graph (FIGURE 14) of the I–V curves of the device made by the present method, the "knee" of each I–V curve is more abrupt, and the "knee" occurs at a lower drain voltage value, than in the plot (FIGURE 13) of I–V curves of a prior art device. This indicates that a larger undistorted output signal can be obtained from the device according to this example than from the prior art device.

Moreover, the individual I–V curves of the device of this example (FIGURE 14) are spaced further apart along the current axis than the I–V curves of the prior art device (FIGURE 13) thus indicating a higher transconductance value for the device of this example than for the prior art device.

Example II

Whereas in Example I, the silicon wafer was P type, and the conductive channel was N type, in this example the semiconductive wafer or slice **10** (FIGURES 1–12) consists of intrinsic silicon having a resistivity of about 100 ohm-cm., and the conductivity modifier diffused into the wafer is an acceptor such as boron. The steps of diffusing the conductivity modifier into selected portions of one wafer face **11** to form a pair of P type source and drain regions **19** and **21** in the wafer, thermally growing a silicon oxide coating **24** on the wafer surface without forming an inversion layer thereon by utilizing pure dry

Figure B.188: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



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oxygen as the ambient while heating the wafer, and forming openings **27** and **28** in the silicon oxide coating **24** on said one wafer face **11** entirely within the surface boundary of the acceptor-diffused wafer regions **19** and **21**, are similar to those described in Example I above. The wafer **10** is now heated in an ambient of ozone at a temperature of about 200° C. to 1000° C. to form a thin P type inversion layer **30** beneath the silicon oxide coating on said one wafer face **11**. The P type inversion layer **30** serves as the conductive channel in the device of this example.

Metallic electrodes **41** and **43** are deposited on the two acceptor-diffused regions **19** and **21**. A metallic gate electrode **42** is deposited on the silicon oxide layer **24** between electrodes **41** and **43**. As in Example I, the gate electrode **42** covers only part of the conductive channel **30**, and is offset so that one end of the gate electrode **42** slightly overlaps the source region, while the other end of the gate electrode extends over part of the conductive channel, leaving the remainder of the channel uncovered.

The wafer **10** is now reheated in an ambient of ozone to increase the conductivity of that portion **34** (FIGURE 11) of the channel **30** which is not covered by the electrode **42**.

The subsequent steps of attaching leads **51, 52** and **53** to electrodes **41, 42** and **43** respectively, subdividing the wafer **10** into a plurality of units, and mounting and casing each unit, are similar to those described in connection with Example I.

The process of the foregoing examples may be utilized to fabricate devices with a wide variety of configurations. For example, the electrode configuration of a semiconductor device may be made circular and concentric, so that an annular gate or control electrode surrounds a central drain electrode, while an annular source electrode in turn surrounds the gate electrode. Alternatively, the source and drain electrodes may be made comb-like or interdigitated in form.

An advantage of the various methods of fabricating semiconductor devices described above is that the conductive channel **30** in each unit formed from a particular semiconductive slice exhibits uniform resistivity from unit to unit. Such uniform resistivity enables the production of a large number of devices with uniform and reproducible electrical characteristics.

Another advantage is that the conductive channel thus prepared is relatively thin, and relatively free from traps, so that current through the channel is easily modulated by the applied field generated by biasing the gate electrode.

Another feature of the invention is that the conductivity of the channel **30** may be monitored and adjusted to the desired values prior to completing the fabrication of the device, thus reducing the amount of scrap. If desired, the conductivity of the channel may be continuously monitored while the silicon body is being heated in a hydrogen-containing ambient, so that the process can be stopped when the desired value is obtained for the conductivity of the channel.

Still another advantage is that the method is simple, rapid, and inexpensive as compared to prior art methods for fabricating such conductive channels.

The embodiments described above are by way of illustration and explanation only, but not limitation. Other dense conductive metals such as tungsten, tantalum, and the like may be utilized for the electrodes instead of gold and silver. The conductive metal may be deposited by electroplating, or by electroless plating, instead of by evaporation. Various other modifications may be made by those skilled in the art without departing from the spirit and scope of the invention as described in the specification and the appended claims.

What is claimed is:

1. The method of forming a conductive channel in a crystalline semiconductive body, comprising the steps of:

forming an insulating coating on one face of said body;

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heating said body in an ambient capable of altering the conductivity of a surface portion thereof to form in said body a conductive channel nuderneath said coating;

depositing a covering metallic electrode on only a portion of said coating, leaving the remaining portion of said coating uncovered; and,

heating said body in an ambient capable of altering the conductivity of that portion of said one face which underlies said coating and is uncovered by said electrode.

2. The method of forming a non-uniform conductive channel in a silicon body, comprising the steps of:

forming an insulating coating on one face of said body by heating said body in a dry oxygen ambient;

heating said body in a reducing ambient to form in said body a conductive channel underneath said coating;

depositing a covering metallic electrode on only a portion of said coating, leaving the remaining portion of said coating uncovered; and,

reheating said body in a reducing ambient to increase the conductivity of that portion of said one face which underlies said coating and is uncovered by said electrode.

3. The method of forming a non-uniform conductive chanel in a monocrystalline silicon wafer, comprising the steps of:

forming a silicon oxide coating on at least one face of said wafer by heating said wafer in a pure dry oxygen ambient;

heating said wafer in an ambient selected from the group consisting of hydrogen and mixtures of hydrogen with nonoxidizing gases to form in said wafer beneath said silicon oxide coating a thin conductive channel immediately adjacent said one face;

depositing a metallic electrode on said silicon oxide coating over a portion only of said conductive channel, leaving the remaining portion of said channel uncovered; and,

reheating said wafer in a hydrogen-containing ambient to increase the conductivity of that portion only of said channel uncovered by said electrode.

4. The method of fabricating a semiconductor device, comprising the steps of:

preparing a high resistivity crystalline semiconductive wafer with two opposing major faces;

depositing an insulating masking coating on at least one said major face;

removing predetermined portions of said coating to expose two spaced areas on said one major face;

forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;

treating said wafer in an ambient capable of altering the conductivity of said one wafer face beneath said coating;

depositing a first conductive electrode on one said exposed area;

depositing a second conductive electrode on the other said exposed area;

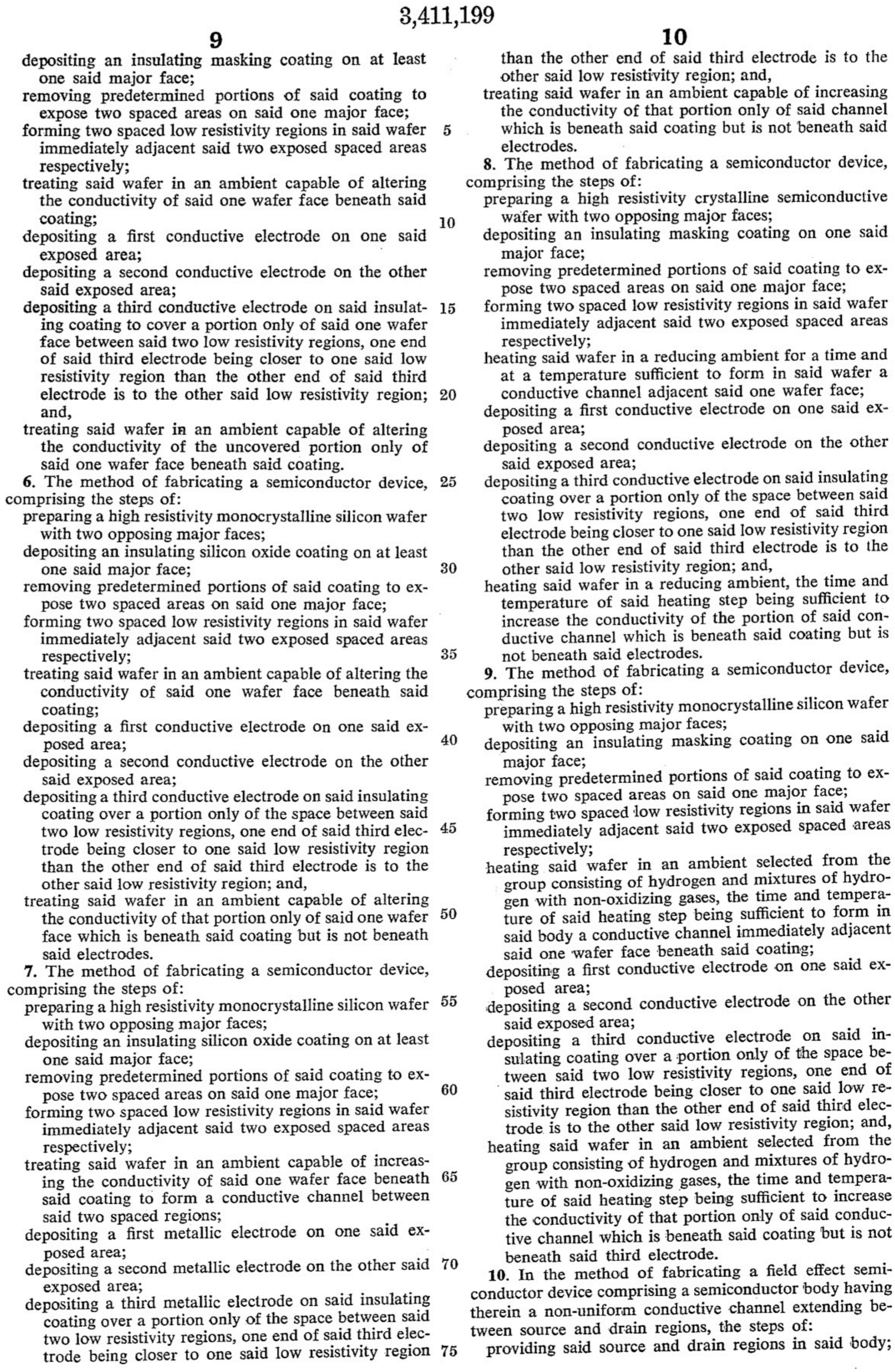
depositing a third conductive electrode on said insulating coating over a portion only of the space between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said electrode is to the other said low resistivity region; and,

treating said wafer in an ambient capable of altering the conductivity of that portion only of said one wafer face which is beneath said coating but is not beneath said electrodes.

5. The method of fabricating a semiconductor device, comprising the steps of:

preparing a high resistivity crystalline silicon wafer with two opposing major faces;

Figure B.189: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



depositing an insulating masking coating on at least one said major face;
removing predetermined portions of said coating to expose two spaced areas on said one major face;
forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;
treating said wafer in an ambient capable of altering the conductivity of said one wafer face beneath said coating;
depositing a first conductive electrode on one said exposed area;
depositing a second conductive electrode on the other said exposed area;
depositing a third conductive electrode on said insulating coating to cover a portion only of said one wafer face between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said third electrode is to the other said low resistivity region; and,
treating said wafer in an ambient capable of altering the conductivity of the uncovered portion only of said one wafer face beneath said coating.

6. The method of fabricating a semiconductor device, comprising the steps of:
preparing a high resistivity monocrystalline silicon wafer with two opposing major faces;
depositing an insulating silicon oxide coating on at least one said major face;
removing predetermined portions of said coating to expose two spaced areas on said one major face;
forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;
treating said wafer in an ambient capable of altering the conductivity of said one wafer face beneath said coating;
depositing a first conductive electrode on one said exposed area;
depositing a second conductive electrode on the other said exposed area;
depositing a third conductive electrode on said insulating coating over a portion only of the space between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said third electrode is to the other said low resistivity region; and,
treating said wafer in an ambient capable of altering the conductivity of that portion only of said one wafer face which is beneath said coating but is not beneath said electrodes.

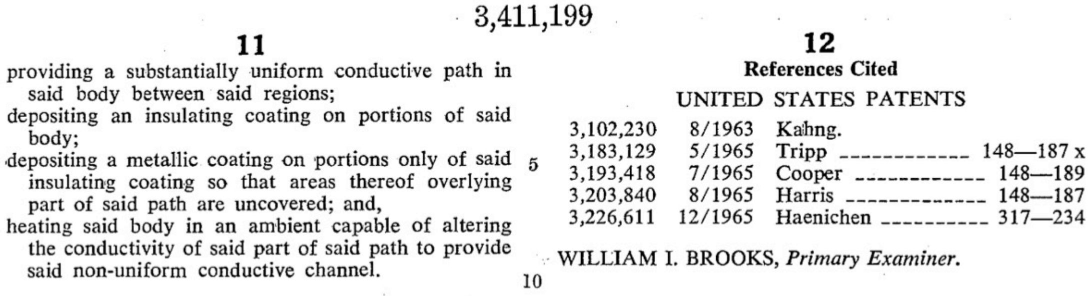
7. The method of fabricating a semiconductor device, comprising the steps of:
preparing a high resistivity monocrystalline silicon wafer with two opposing major faces;
depositing an insulating silicon oxide coating on at least one said major face;
removing predetermined portions of said coating to expose two spaced areas on said one major face;
forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;
treating said wafer in an ambient capable of increasing the conductivity of said one wafer face beneath said coating to form a conductive channel between said two spaced regions;
depositing a first metallic electrode on one said exposed area;
depositing a second metallic electrode on the other said exposed area;
depositing a third metallic electrode on said insulating coating over a portion only of the space between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said third electrode is to the other said low resistivity region; and,
treating said wafer in an ambient capable of increasing the conductivity of that portion only of said channel which is beneath said coating but is not beneath said electrodes.

8. The method of fabricating a semiconductor device, comprising the steps of:
preparing a high resistivity crystalline semiconductive wafer with two opposing major faces;
depositing an insulating masking coating on one said major face;
removing predetermined portions of said coating to expose two spaced areas on said one major face;
forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;
heating said wafer in a reducing ambient for a time and at a temperature sufficient to form in said wafer a conductive channel adjacent said one wafer face;
depositing a first conductive electrode on one said exposed area;
depositing a second conductive electrode on the other said exposed area;
depositing a third conductive electrode on said insulating coating over a portion only of the space between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said third electrode is to the other said low resistivity region; and,
heating said wafer in a reducing ambient, the time and temperature of said heating step being sufficient to increase the conductivity of the portion of said conductive channel which is beneath said coating but is not beneath said electrodes.

9. The method of fabricating a semiconductor device, comprising the steps of:
preparing a high resistivity monocrystalline silicon wafer with two opposing major faces;
depositing an insulating masking coating on one said major face;
removing predetermined portions of said coating to expose two spaced areas on said one major face;
forming two spaced low resistivity regions in said wafer immediately adjacent said two exposed spaced areas respectively;
heating said wafer in an ambient selected from the group consisting of hydrogen and mixtures of hydrogen with non-oxidizing gases, the time and temperature of said heating step being sufficient to form in said body a conductive channel immediately adjacent said one wafer face beneath said coating;
depositing a first conductive electrode on one said exposed area;
depositing a second conductive electrode on the other said exposed area;
depositing a third conductive electrode on said insulating coating over a portion only of the space between said two low resistivity regions, one end of said third electrode being closer to one said low resistivity region than the other end of said third electrode is to the other said low resistivity region; and,
heating said wafer in an ambient selected from the group consisting of hydrogen and mixtures of hydrogen with non-oxidizing gases, the time and temperature of said heating step being sufficient to increase the conductivity of that portion only of said conductive channel which is beneath said coating but is not beneath said third electrode.

10. In the method of fabricating a field effect semiconductor device comprising a semiconductor body having therein a non-uniform conductive channel extending between source and drain regions, the steps of:
providing said source and drain regions in said body;

Figure B.190: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



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providing a substantially uniform conductive path in said body between said regions;

depositing an insulating coating on portions of said body;

depositing a metallic coating on portions only of said insulating coating so that areas thereof overlying part of said path are uncovered; and,

heating said body in an ambient capable of altering the conductivity of said part of said path to provide said non-uniform conductive channel.

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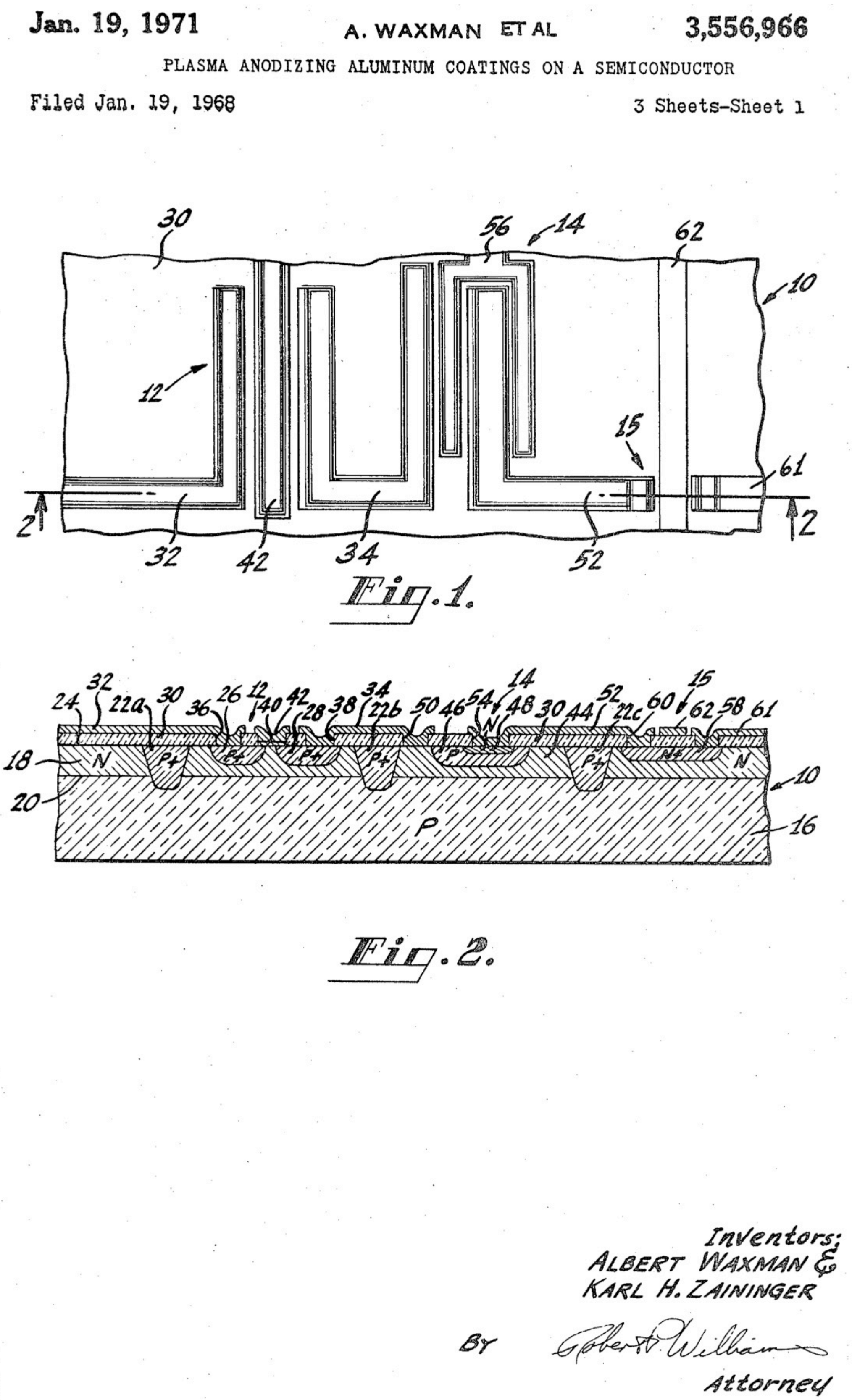
WILLIAM I. BROOKS, *Primary Examiner.*

Figure B.191: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



Jan. 19, 1971 A. WAXMAN ET AL **3,556,966**

PLASMA ANODIZING ALUMINUM COATINGS ON A SEMICONDUCTOR

Filed Jan. 19, 1968 3 Sheets-Sheet 1

Fig. 1.

Fig. 2.

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Figure B.192: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.

Jan. 19, 1971 A. WAXMAN ET AL **3,556,966**

PLASMA ANODIZING ALUMINUM COATINGS ON A SEMICONDUCTOR

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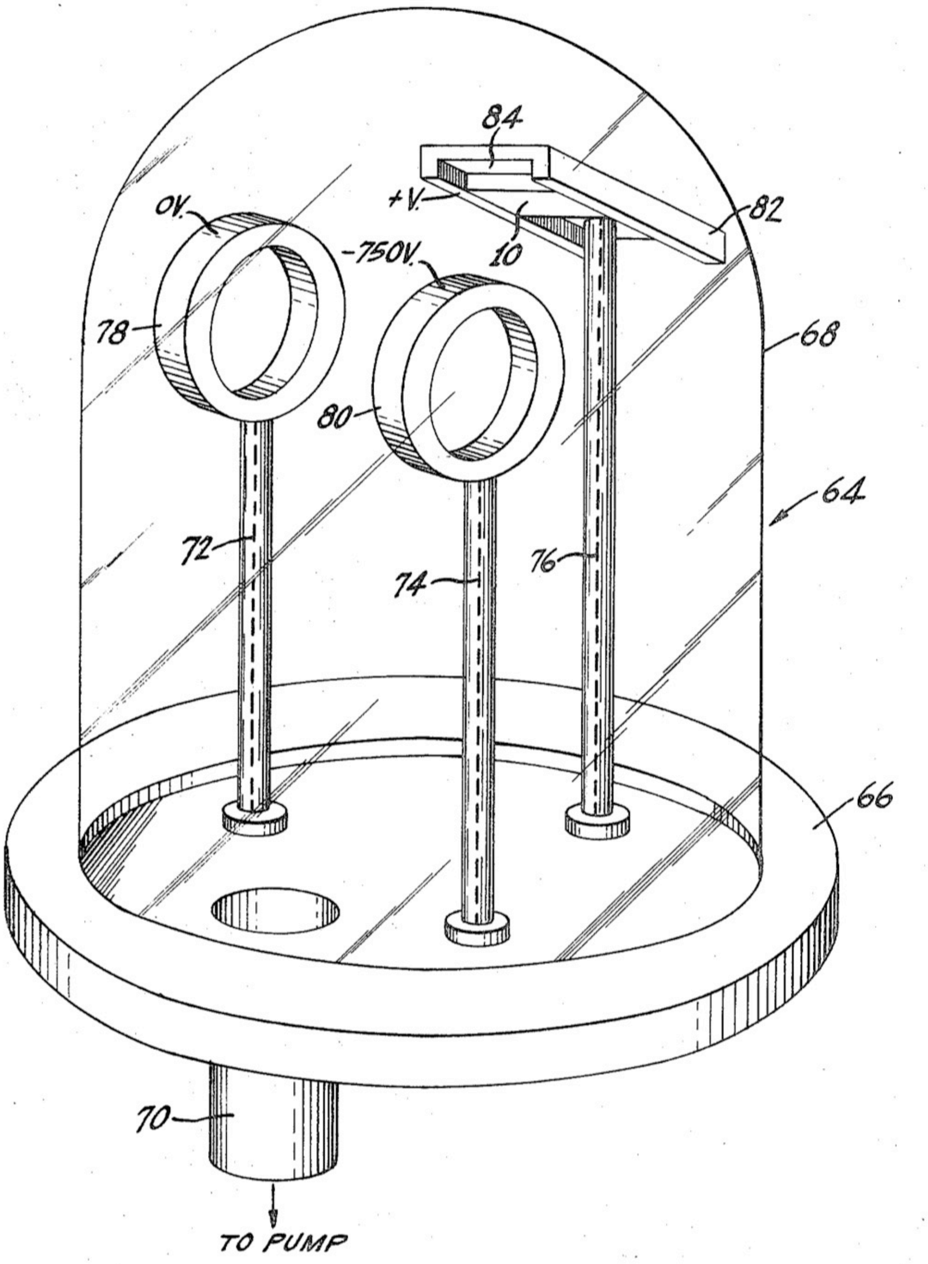

Fig. 3.

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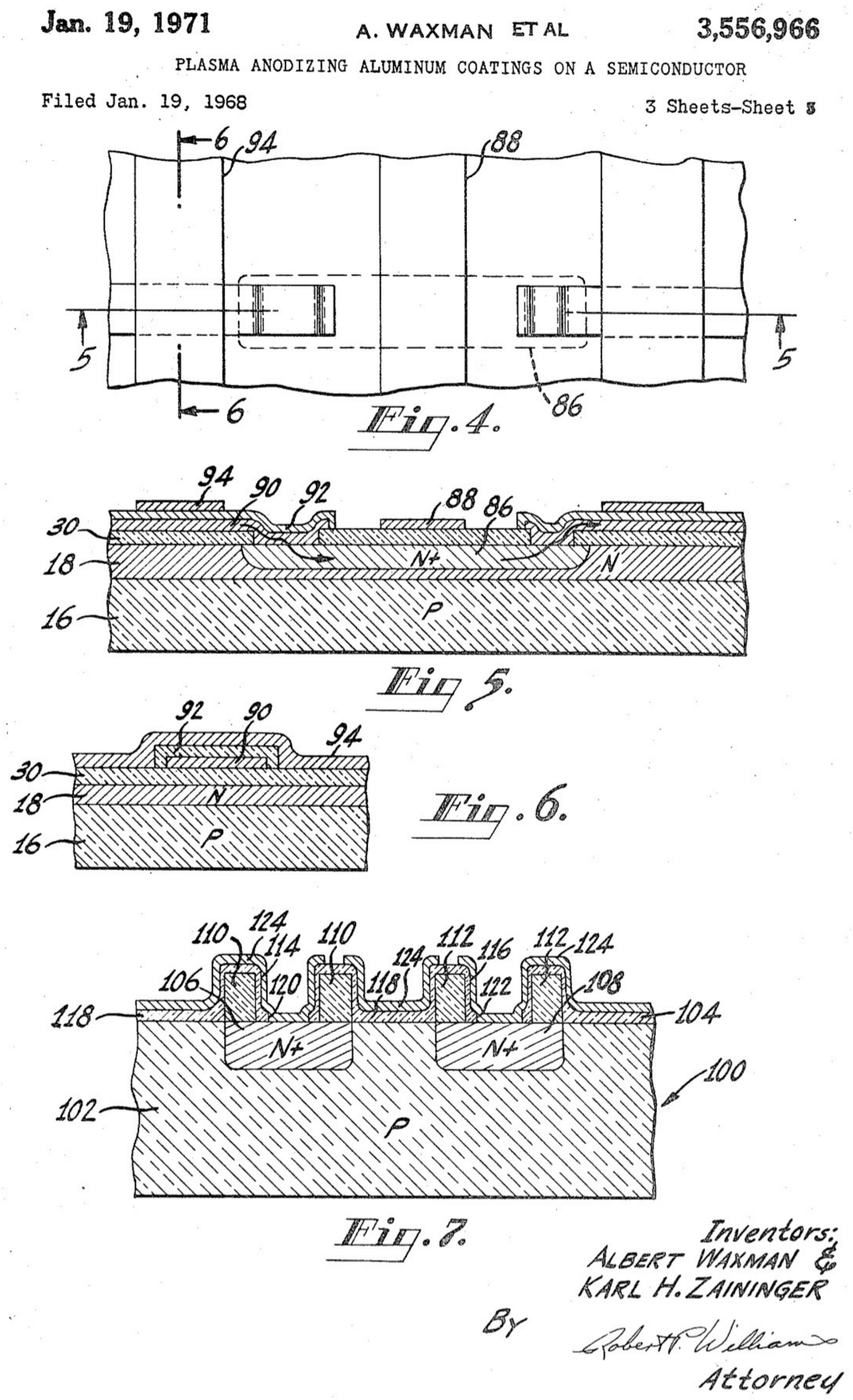
Figure B.193: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



Jan. 19, 1971 A. WAXMAN ET AL **3,556,966**

PLASMA ANODIZING ALUMINUM COATINGS ON A SEMICONDUCTOR

Filed Jan. 19, 1968 3 Sheets-Sheet 3

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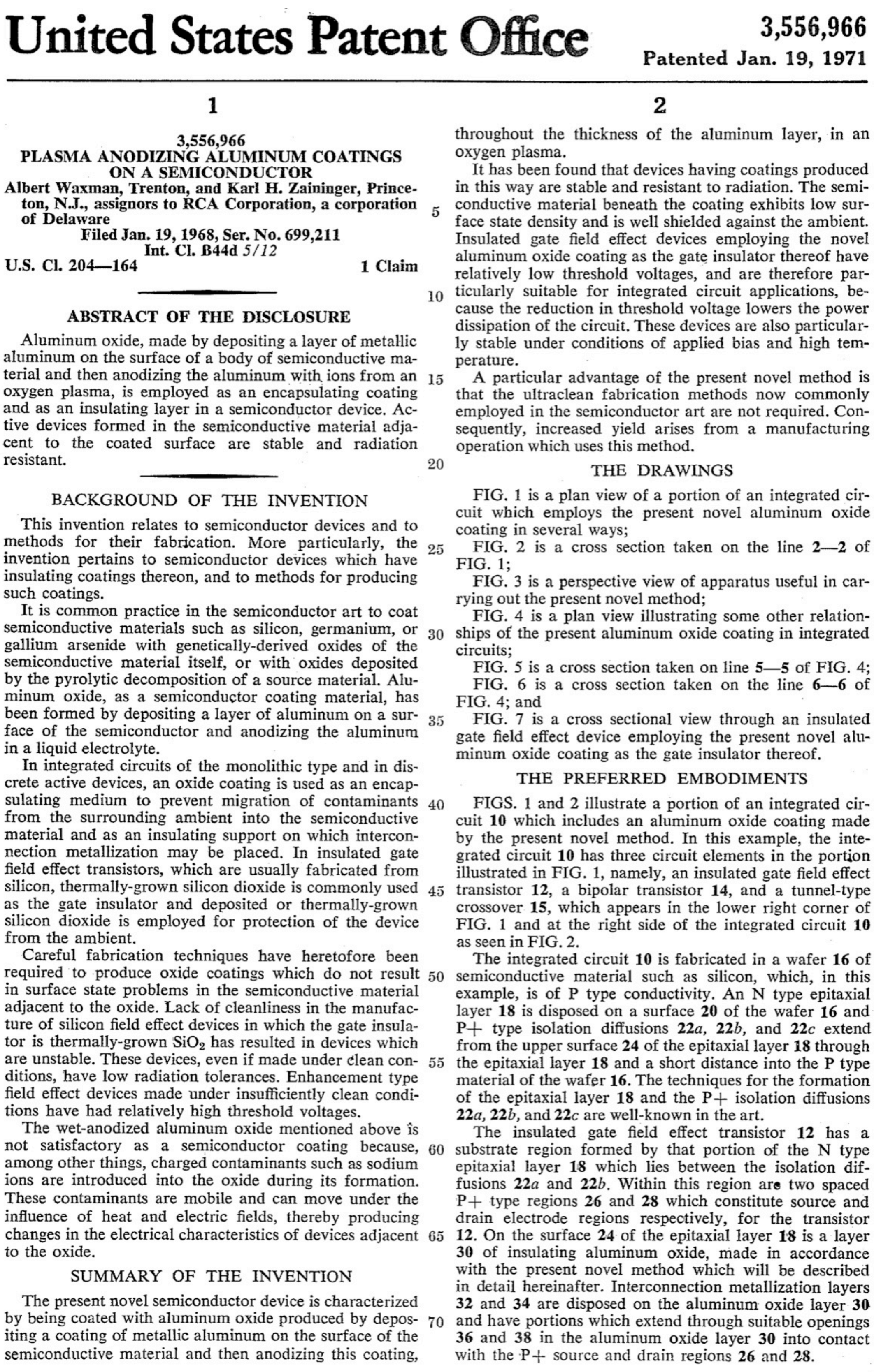
Figure B.194: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



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3,556,966

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PLASMA ANODIZING ALUMINUM COATINGS ON A SEMICONDUCTOR

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Filed Jan. 19, 1968, Ser. No. 699,211
Int. Cl. B44d *5/12*
U.S. Cl. 204—164 **1 Claim**

ABSTRACT OF THE DISCLOSURE

Aluminum oxide, made by depositing a layer of metallic aluminum on the surface of a body of semiconductive material and then anodizing the aluminum with ions from an oxygen plasma, is employed as an encapsulating coating and as an insulating layer in a semiconductor device. Active devices formed in the semiconductive material adjacent to the coated surface are stable and radiation resistant.

BACKGROUND OF THE INVENTION

This invention relates to semiconductor devices and to methods for their fabrication. More particularly, the invention pertains to semiconductor devices which have insulating coatings thereon, and to methods for producing such coatings.

It is common practice in the semiconductor art to coat semiconductive materials such as silicon, germanium, or gallium arsenide with genetically-derived oxides of the semiconductive material itself, or with oxides deposited by the pyrolytic decomposition of a source material. Aluminum oxide, as a semiconductor coating material, has been formed by depositing a layer of aluminum on a surface of the semiconductor and anodizing the aluminum in a liquid electrolyte.

In integrated circuits of the monolithic type and in discrete active devices, an oxide coating is used as an encapsulating medium to prevent migration of contaminants from the surrounding ambient into the semiconductive material and as an insulating support on which interconnection metallization may be placed. In insulated gate field effect transistors, which are usually fabricated from silicon, thermally-grown silicon dioxide is commonly used as the gate insulator and deposited or thermally-grown silicon dioxide is employed for protection of the device from the ambient.

Careful fabrication techniques have heretofore been required to produce oxide coatings which do not result in surface state problems in the semiconductive material adjacent to the oxide. Lack of cleanliness in the manufacture of silicon field effect devices in which the gate insulator is thermally-grown SiO_2 has resulted in devices which are unstable. These devices, even if made under clean conditions, have low radiation tolerances. Enhancement type field effect devices made under insufficiently clean conditions have had relatively high threshold voltages.

The wet-anodized aluminum oxide mentioned above is not satisfactory as a semiconductor coating because, among other things, charged contaminants such as sodium ions are introduced into the oxide during its formation. These contaminants are mobile and can move under the influence of heat and electric fields, thereby producing changes in the electrical characteristics of devices adjacent to the oxide.

SUMMARY OF THE INVENTION

The present novel semiconductor device is characterized by being coated with aluminum oxide produced by depositing a coating of metallic aluminum on the surface of the semiconductive material and then anodizing this coating, throughout the thickness of the aluminum layer, in an oxygen plasma.

It has been found that devices having coatings produced in this way are stable and resistant to radiation. The semiconductive material beneath the coating exhibits low surface state density and is well shielded against the ambient. Insulated gate field effect devices employing the novel aluminum oxide coating as the gate insulator thereof have relatively low threshold voltages, and are therefore particularly suitable for integrated circuit applications, because the reduction in threshold voltage lowers the power dissipation of the circuit. These devices are also particularly stable under conditions of applied bias and high temperature.

A particular advantage of the present novel method is that the ultraclean fabrication methods now commonly employed in the semiconductor art are not required. Consequently, increased yield arises from a manufacturing operation which uses this method.

THE DRAWINGS

FIG. 1 is a plan view of a portion of an integrated circuit which employs the present novel aluminum oxide coating in several ways;

FIG. 2 is a cross section taken on the line **2—2** of FIG. 1;

FIG. 3 is a perspective view of apparatus useful in carrying out the present novel method;

FIG. 4 is a plan view illustrating some other relationships of the present aluminum oxide coating in integrated circuits;

FIG. 5 is a cross section taken on line **5—5** of FIG. 4;

FIG. 6 is a cross section taken on the line **6—6** of FIG. 4; and

FIG. 7 is a cross sectional view through an insulated gate field effect device employing the present novel aluminum oxide coating as the gate insulator thereof.

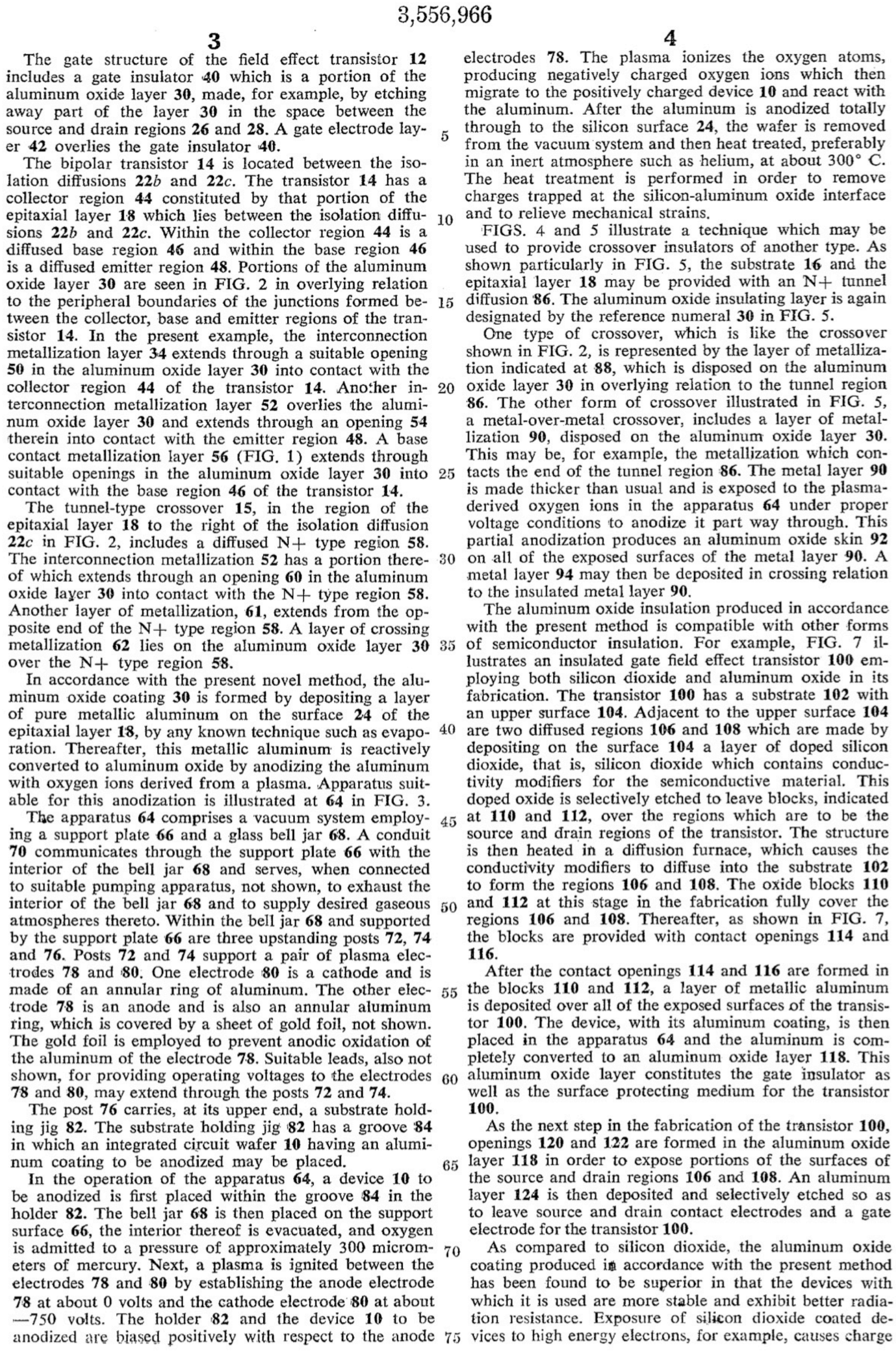
THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 illustrate a portion of an integrated circuit **10** which includes an aluminum oxide coating made by the present novel method. In this example, the integrated circuit **10** has three circuit elements in the portion illustrated in FIG. 1, namely, an insulated gate field effect transistor **12**, a bipolar transistor **14**, and a tunnel-type crossover **15**, which appears in the lower right corner of FIG. 1 and at the right side of the integrated circuit **10** as seen in FIG. 2.

The integrated circuit **10** is fabricated in a wafer **16** of semiconductive material such as silicon, which, in this example, is of P type conductivity. An N type epitaxial layer **18** is disposed on a surface **20** of the wafer **16** and P+ type isolation diffusions **22***a*, **22***b*, and **22***c* extend from the upper surface **24** of the epitaxial layer **18** through the epitaxial layer **18** and a short distance into the P type material of the wafer **16**. The techniques for the formation of the epitaxial layer **18** and the P+ isolation diffusions **22***a*, **22***b*, and **22***c* are well-known in the art.

The insulated gate field effect transistor **12** has a substrate region formed by that portion of the N type epitaxial layer **18** which lies between the isolation diffusions **22***a* and **22***b*. Within this region are two spaced P+ type regions **26** and **28** which constitute source and drain electrode regions respectively, for the transistor **12**. On the surface **24** of the epitaxial layer **18** is a layer **30** of insulating aluminum oxide, made in accordance with the present novel method which will be described in detail hereinafter. Interconnection metallization layers **32** and **34** are disposed on the aluminum oxide layer **30** and have portions which extend through suitable openings **36** and **38** in the aluminum oxide layer **30** into contact with the P+ source and drain regions **26** and **28**.

Figure B.195: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



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The gate structure of the field effect transistor **12** includes a gate insulator **40** which is a portion of the aluminum oxide layer **30**, made, for example, by etching away part of the layer **30** in the space between the source and drain regions **26** and **28**. A gate electrode layer **42** overlies the gate insulator **40**.

The bipolar transistor **14** is located between the isolation diffusions **22***b* and **22***c*. The transistor **14** has a collector region **44** constituted by that portion of the epitaxial layer **18** which lies between the isolation diffusions **22***b* and **22***c*. Within the collector region **44** is a diffused base region **46** and within the base region **46** is a diffused emitter region **48**. Portions of the aluminum oxide layer **30** are seen in FIG. 2 in overlying relation to the peripheral boundaries of the junctions formed between the collector, base and emitter regions of the transistor **14**. In the present example, the interconnection metallization layer **34** extends through a suitable opening **50** in the aluminum oxide layer **30** into contact with the collector region **44** of the transistor **14**. Another interconnection metallization layer **52** overlies the aluminum oxide layer **30** and extends through an opening **54** therein into contact with the emitter region **48**. A base contact metallization layer **56** (FIG. 1) extends through suitable openings in the aluminum oxide layer **30** into contact with the base region **46** of the transistor **14**.

The tunnel-type crossover **15**, in the region of the epitaxial layer **18** to the right of the isolation diffusion **22***c* in FIG. 2, includes a diffused N+ type region **58**. The interconnection metallization **52** has a portion thereof which extends through an opening **60** in the aluminum oxide layer **30** into contact with the N+ type region **58**. Another layer of metallization, **61**, extends from the opposite end of the N+ type region **58**. A layer of crossing metallization **62** lies on the aluminum oxide layer **30** over the N+ type region **58**.

In accordance with the present novel method, the aluminum oxide coating **30** is formed by depositing a layer of pure metallic aluminum on the surface **24** of the epitaxial layer **18**, by any known technique such as evaporation. Thereafter, this metallic aluminum is reactively converted to aluminum oxide by anodizing the aluminum with oxygen ions derived from a plasma. Apparatus suitable for this anodization is illustrated at **64** in FIG. 3.

The apparatus **64** comprises a vacuum system employing a support plate **66** and a glass bell jar **68**. A conduit **70** communicates through the support plate **66** with the interior of the bell jar **68** and serves, when connected to suitable pumping apparatus, not shown, to exhaust the interior of the bell jar **68** and to supply desired gaseous atmospheres thereto. Within the bell jar **68** and supported by the support plate **66** are three upstanding posts **72**, **74** and **76**. Posts **72** and **74** support a pair of plasma electrodes **78** and **80**. One electrode **80** is a cathode and is made of an annular ring of aluminum. The other electrode **78** is an anode and is also an annular aluminum ring, which is covered by a sheet of gold foil, not shown. The gold foil is employed to prevent anodic oxidation of the aluminum of the electrode **78**. Suitable leads, also not shown, for providing operating voltages to the electrodes **78** and **80**, may extend through the posts **72** and **74**.

The post **76** carries, at its upper end, a substrate holding jig **82**. The substrate holding jig **82** has a groove **84** in which an integrated circuit wafer **10** having an aluminum coating to be anodized may be placed.

In the operation of the apparatus **64**, a device **10** to be anodized is first placed within the groove **84** in the holder **82**. The bell jar **68** is then placed on the support surface **66**, the interior thereof is evacuated, and oxygen is admitted to a pressure of approximately 300 micrometers of mercury. Next, a plasma is ignited between the electrodes **78** and **80** by establishing the anode electrode **78** at about 0 volts and the cathode electrode **80** at about −750 volts. The holder **82** and the device **10** to be anodized are biased positively with respect to the anode electrodes **78**. The plasma ionizes the oxygen atoms, producing negatively charged oxygen ions which then migrate to the positively charged device **10** and react with the aluminum. After the aluminum is anodized totally through to the silicon surface **24**, the wafer is removed from the vacuum system and then heat treated, preferably in an inert atmosphere such as helium, at about 300° C. The heat treatment is performed in order to remove charges trapped at the silicon-aluminum oxide interface and to relieve mechanical strains.

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FIGS. 4 and 5 illustrate a technique which may be used to provide crossover insulators of another type. As shown particularly in FIG. 5, the substrate **16** and the epitaxial layer **18** may be provided with an N+ tunnel diffusion **86**. The aluminum oxide insulating layer is again designated by the reference numeral **30** in FIG. 5.

One type of crossover, which is like the crossover shown in FIG. 2, is represented by the layer of metallization indicated at **88**, which is disposed on the aluminum oxide layer **30** in overlying relation to the tunnel region **86**. The other form of crossover illustrated in FIG. 5, a metal-over-metal crossover, includes a layer of metallization **90**, disposed on the aluminum oxide layer **30**. This may be, for example, the metallization which contacts the end of the tunnel region **86**. The metal layer **90** is made thicker than usual and is exposed to the plasma-derived oxygen ions in the apparatus **64** under proper voltage conditions to anodize it part way through. This partial anodization produces an aluminum oxide skin **92** on all of the exposed surfaces of the metal layer **90**. A metal layer **94** may then be deposited in crossing relation to the insulated metal layer **90**.

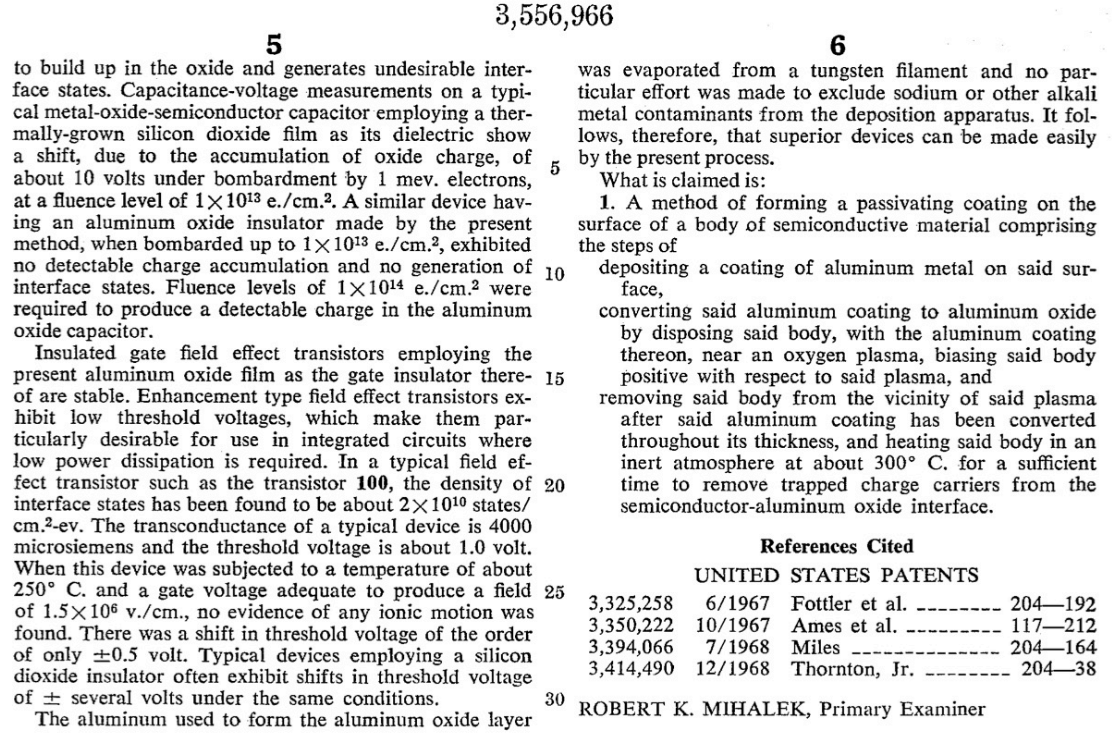
The aluminum oxide insulation produced in accordance with the present method is compatible with other forms of semiconductor insulation. For example, FIG. 7 illustrates an insulated gate field effect transistor **100** employing both silicon dioxide and aluminum oxide in its fabrication. The transistor **100** has a substrate **102** with an upper surface **104**. Adjacent to the upper surface **104** are two diffused regions **106** and **108** which are made by depositing on the surface **104** a layer of doped silicon dioxide, that is, silicon dioxide which contains conductivity modifiers for the semiconductive material. This doped oxide is selectively etched to leave blocks, indicated at **110** and **112**, over the regions which are to be the source and drain regions of the transistor. The structure is then heated in a diffusion furnace, which causes the conductivity modifiers to diffuse into the substrate **102** to form the regions **106** and **108**. The oxide blocks **110** and **112** at this stage in the fabrication fully cover the regions **106** and **108**. Thereafter, as shown in FIG. 7, the blocks are provided with contact openings **114** and **116**.

After the contact openings **114** and **116** are formed in the blocks **110** and **112**, a layer of metallic aluminum is deposited over all of the exposed surfaces of the transistor **100**. The device, with its aluminum coating, is then placed in the apparatus **64** and the aluminum is completely converted to an aluminum oxide layer **118**. This aluminum oxide layer constitutes the gate insulator as well as the surface protecting medium for the transistor **100**.

As the next step in the fabrication of the transistor **100**, openings **120** and **122** are formed in the aluminum oxide layer **118** in order to expose portions of the surfaces of the source and drain regions **106** and **108**. An aluminum layer **124** is then deposited and selectively etched so as to leave source and drain contact electrodes and a gate electrode for the transistor **100**.

As compared to silicon dioxide, the aluminum oxide coating produced in accordance with the present method has been found to be superior in that the devices with which it is used are more stable and exhibit better radiation resistance. Exposure of silicon dioxide coated devices to high energy electrons, for example, causes charge

Figure B.196: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



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to build up in the oxide and generates undesirable interface states. Capacitance-voltage measurements on a typical metal-oxide-semiconductor capacitor employing a thermally-grown silicon dioxide film as its dielectric show a shift, due to the accumulation of oxide charge, of about 10 volts under bombardment by 1 mev. electrons, at a fluence level of 1×10^{13} e./cm.^{2}. A similar device having an aluminum oxide insulator made by the present method, when bombarded up to 1×10^{13} e./cm.^{2}, exhibited no detectable charge accumulation and no generation of interface states. Fluence levels of 1×10^{14} e./cm.^{2} were required to produce a detectable charge in the aluminum oxide capacitor.

Insulated gate field effect transistors employing the present aluminum oxide film as the gate insulator thereof are stable. Enhancement type field effect transistors exhibit low threshold voltages, which make them particularly desirable for use in integrated circuits where low power dissipation is required. In a typical field effect transistor such as the transistor **100**, the density of interface states has been found to be about 2×10^{10} states/cm.^{2}-ev. The transconductance of a typical device is 4000 microsiemens and the threshold voltage is about 1.0 volt. When this device was subjected to a temperature of about 250° C. and a gate voltage adequate to produce a field of 1.5×10^6 v./cm., no evidence of any ionic motion was found. There was a shift in threshold voltage of the order of only ±0.5 volt. Typical devices employing a silicon dioxide insulator often exhibit shifts in threshold voltage of ± several volts under the same conditions.

The aluminum used to form the aluminum oxide layer

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was evaporated from a tungsten filament and no particular effort was made to exclude sodium or other alkali metal contaminants from the deposition apparatus. It follows, therefore, that superior devices can be made easily by the present process.

What is claimed is:

1. A method of forming a passivating coating on the surface of a body of semiconductive material comprising the steps of

depositing a coating of aluminum metal on said surface,

converting said aluminum coating to aluminum oxide by disposing said body, with the aluminum coating thereon, near an oxygen plasma, biasing said body positive with respect to said plasma, and

removing said body from the vicinity of said plasma after said aluminum coating has been converted throughout its thickness, and heating said body in an inert atmosphere at about 300° C. for a sufficient time to remove trapped charge carriers from the semiconductor-aluminum oxide interface.

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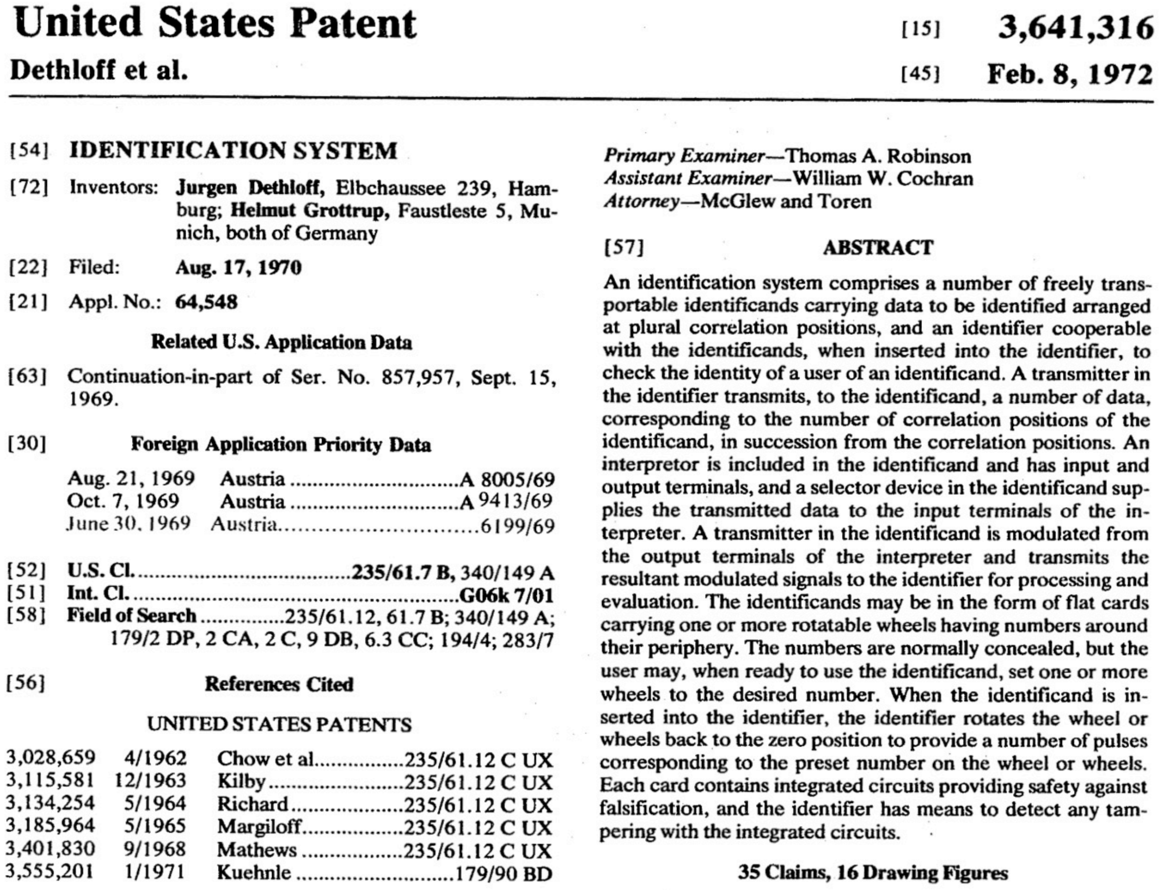
ROBERT K. MIHALEK, Primary Examiner

Figure B.197: Karl Heinz Zaininger invented methods of manufacturing field effect transistors.



United States Patent [15] **3,641,316**

Dethloff et al. [45] **Feb. 8, 1972**

[54] **IDENTIFICATION SYSTEM**

[72] Inventors: **Jurgen Dethloff,** Elbchaussee 239, Hamburg; **Helmut Grottrup,** Faustleste 5, Munich, both of Germany

[22] Filed: **Aug. 17, 1970**

[21] Appl. No.: **64,548**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 857,957, Sept. 15, 1969.

[30] **Foreign Application Priority Data**

Aug. 21, 1969	Austria	A 8005/69
Oct. 7, 1969	Austria	A 9413/69
June 30, 1969	Austria	6199/69

[52] **U.S. Cl.** ....**235/61.7 B,** 340/149 A
[51] **Int. Cl.** **G06k 7/01**
[58] **Field of Search** ....235/61.12, 61.7 B; 340/149 A; 179/2 DP, 2 CA, 2 C, 9 DB, 6.3 CC; 194/4; 283/7

[56] **References Cited**

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Primary Examiner—Thomas A. Robinson
Assistant Examiner—William W. Cochran
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[57] **ABSTRACT**

An identification system comprises a number of freely transportable identificands carrying data to be identified arranged at plural correlation positions, and an identifier cooperable with the identificands, when inserted into the identifier, to check the identity of a user of an identificand. A transmitter in the identifier transmits, to the identificand, a number of data, corresponding to the number of correlation positions of the identificand, in succession from the correlation positions. An interpretor is included in the identificand and has input and output terminals, and a selector device in the identificand supplies the transmitted data to the input terminals of the interpreter. A transmitter in the identificand is modulated from the output terminals of the interpreter and transmits the resultant modulated signals to the identifier for processing and evaluation. The identificands may be in the form of flat cards carrying one or more rotatable wheels having numbers around their periphery. The numbers are normally concealed, but the user may, when ready to use the identificand, set one or more wheels to the desired number. When the identificand is inserted into the identifier, the identifier rotates the wheel or wheels back to the zero position to provide a number of pulses corresponding to the preset number on the wheel or wheels. Each card contains integrated circuits providing safety against falsification, and the identifier has means to detect any tampering with the integrated circuits.

35 Claims, 16 Drawing Figures

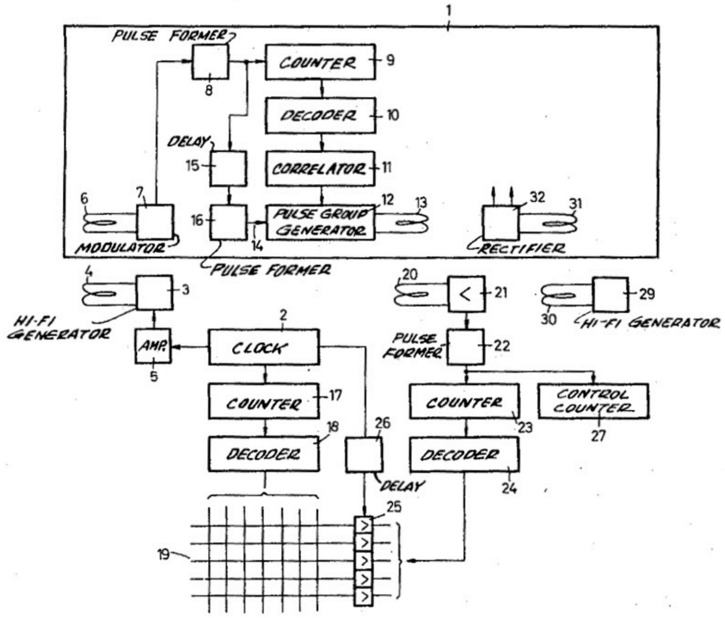

Figure B.198: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

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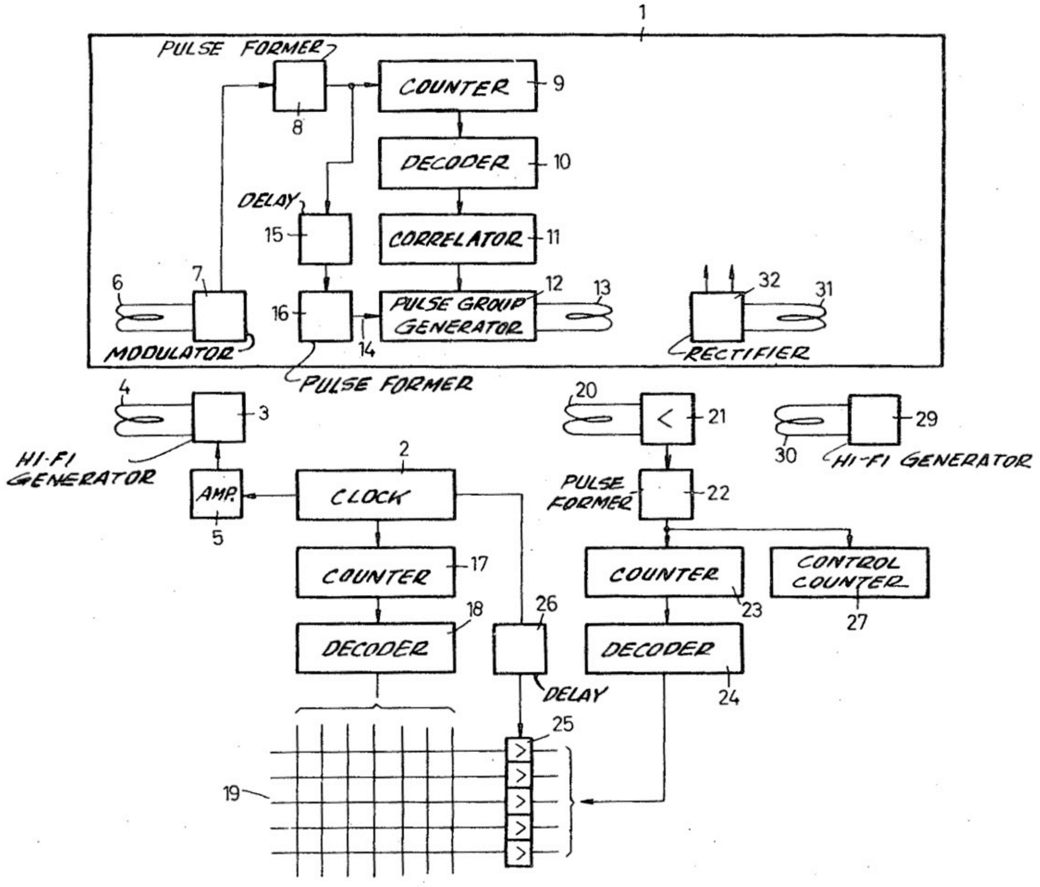

Fig.1

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ATTORNEYS

Figure B.199: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

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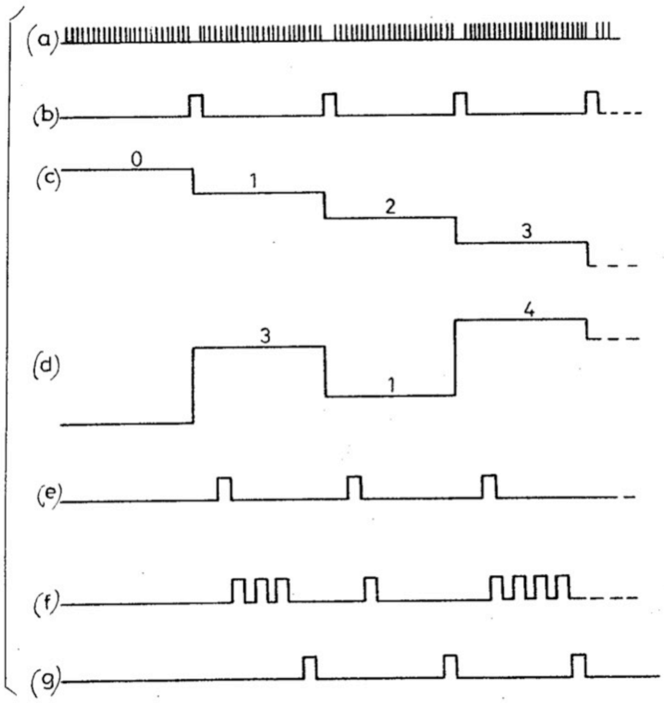

Fig.2

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Figure B.200: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

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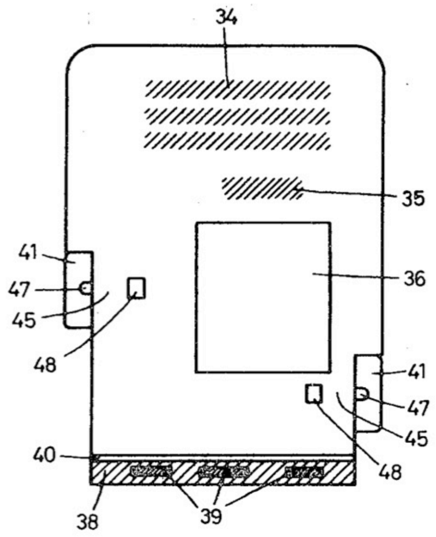

Fig.3

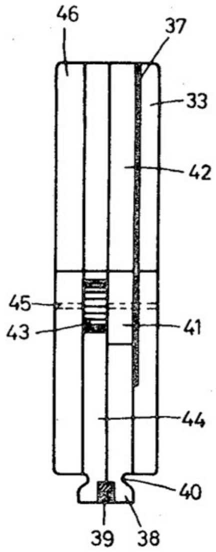

Fig.4

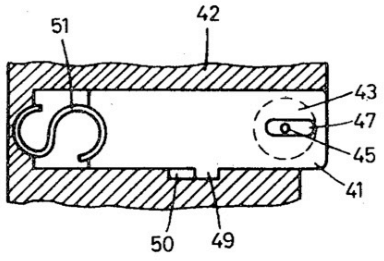

Fig.5

INVENTORS
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BY McGlew & Toren
ATTORNEYS

Figure B.201: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

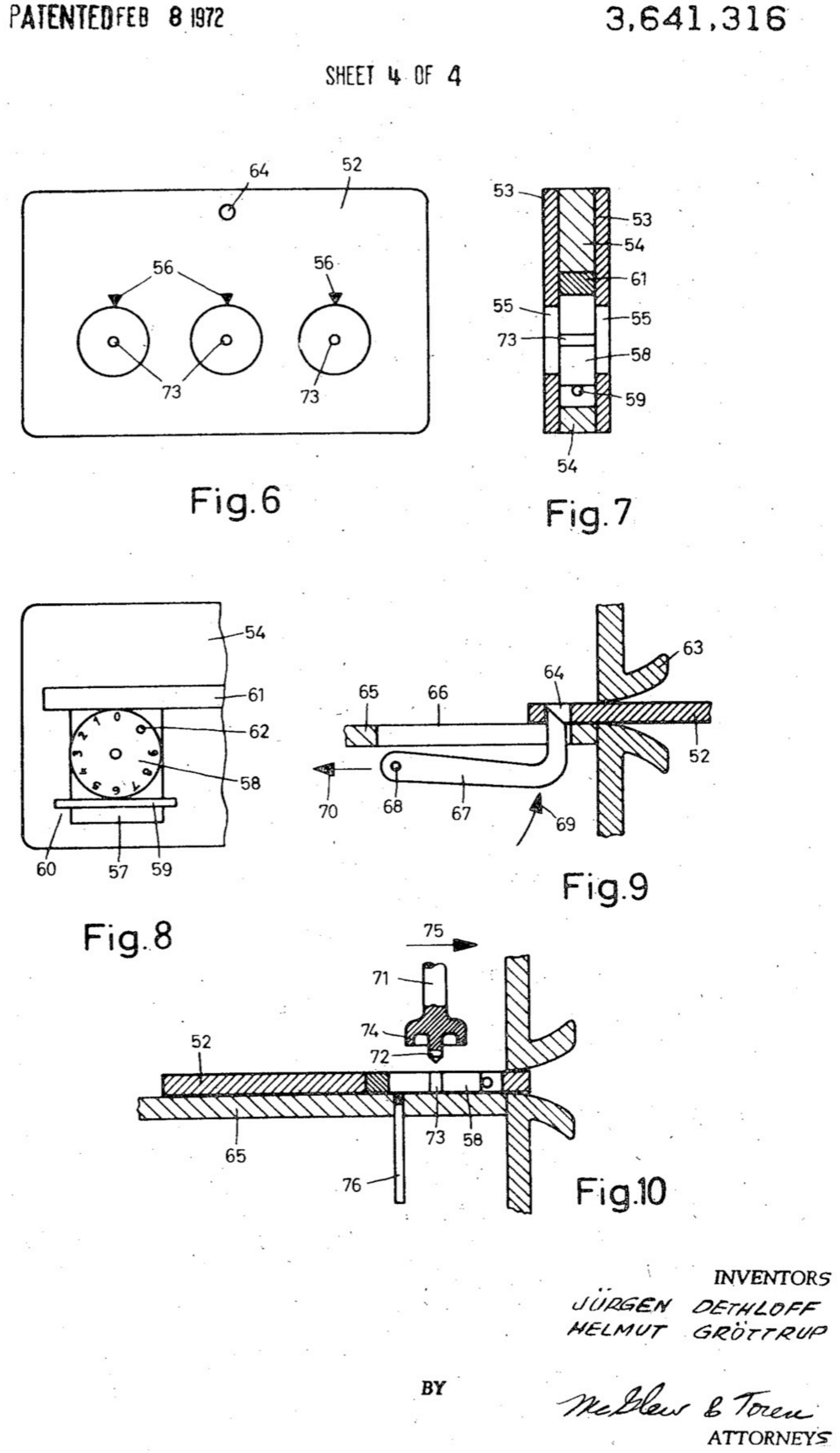
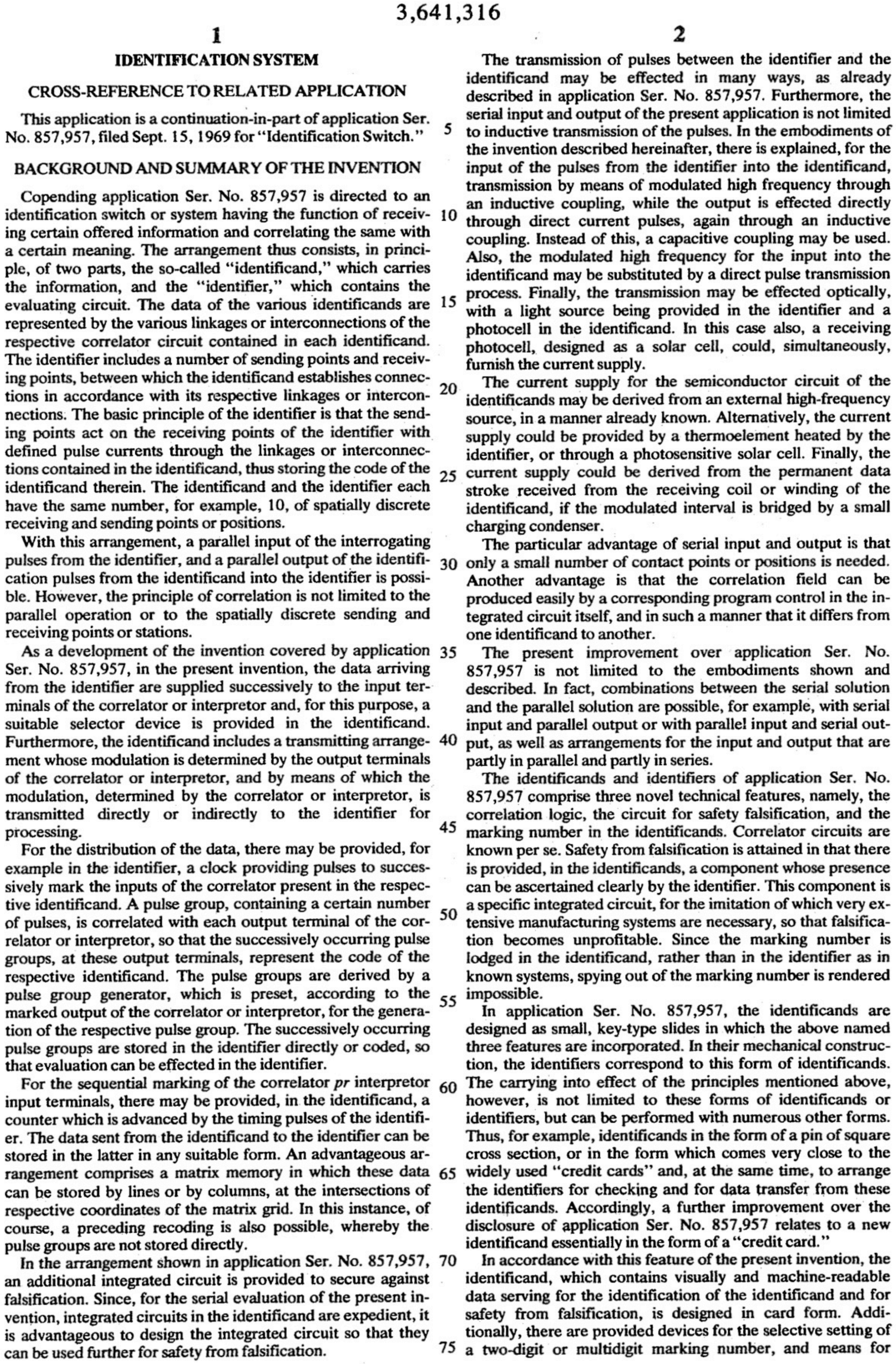


Figure B.202: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.



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IDENTIFICATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of application Ser. No. 857,957, filed Sept. 15, 1969 for "Identification Switch."

BACKGROUND AND SUMMARY OF THE INVENTION

Copending application Ser. No. 857,957 is directed to an identification switch or system having the function of receiving certain offered information and correlating the same with a certain meaning. The arrangement thus consists, in principle, of two parts, the so-called "identificand," which carries the information, and the "identifier," which contains the evaluating circuit. The data of the various identificands are represented by the various linkages or interconnections of the respective correlator circuit contained in each identificand. The identifier includes a number of sending points and receiving points, between which the identificand establishes connections in accordance with its respective linkages or interconnections. The basic principle of the identifier is that the sending points act on the receiving points of the identifier with defined pulse currents through the linkages or interconnections contained in the identificand, thus storing the code of the identificand therein. The identificand and the identifier each have the same number, for example, 10, of spatially discrete receiving and sending points or positions.

With this arrangement, a parallel input of the interrogating pulses from the identifier, and a parallel output of the identification pulses from the identificand into the identifier is possible. However, the principle of correlation is not limited to the parallel operation or to the spatially discrete sending and receiving points or stations.

As a development of the invention covered by application Ser. No. 857,957, in the present invention, the data arriving from the identifier are supplied successively to the input terminals of the correlator or interpretor and, for this purpose, a suitable selector device is provided in the identificand. Furthermore, the identificand includes a transmitting arrangement whose modulation is determined by the output terminals of the correlator or interpretor, and by means of which the modulation, determined by the correlator or interpretor, is transmitted directly or indirectly to the identifier for processing.

For the distribution of the data, there may be provided, for example in the identifier, a clock providing pulses to successively mark the inputs of the correlator present in the respective identificand. A pulse group, containing a certain number of pulses, is correlated with each output terminal of the correlator or interpretor, so that the successively occurring pulse groups, at these output terminals, represent the code of the respective identificand. The pulse groups are derived by a pulse group generator, which is preset, according to the marked output of the correlator or interpretor, for the generation of the respective pulse group. The successively occurring pulse groups are stored in the identifier directly or coded, so that evaluation can be effected in the identifier.

For the sequential marking of the correlator *pr* interpretor input terminals, there may be provided, in the identificand, a counter which is advanced by the timing pulses of the identifier. The data sent from the identificand to the identifier can be stored in the latter in any suitable form. An advantageous arrangement comprises a matrix memory in which these data can be stored by lines or by columns, at the intersections of respective coordinates of the matrix grid. In this instance, of course, a preceding recoding is also possible, whereby the pulse groups are not stored directly.

In the arrangement shown in application Ser. No. 857,957, an additional integrated circuit is provided to secure against falsification. Since, for the serial evaluation of the present invention, integrated circuits in the identificand are expedient, it is advantageous to design the integrated circuit so that they can be used further for safety from falsification.

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The transmission of pulses between the identifier and the identificand may be effected in many ways, as already described in application Ser. No. 857,957. Furthermore, the serial input and output of the present application is not limited to inductive transmission of the pulses. In the embodiments of the invention described hereinafter, there is explained, for the input of the pulses from the identifier into the identificand, transmission by means of modulated high frequency through an inductive coupling, while the output is effected directly through direct current pulses, again through an inductive coupling. Instead of this, a capacitive coupling may be used. Also, the modulated high frequency for the input into the identificand may be substituted by a direct pulse transmission process. Finally, the transmission may be effected optically, with a light source being provided in the identifier and a photocell in the identificand. In this case also, a receiving photocell, designed as a solar cell, could, simultaneously, furnish the current supply.

The current supply for the semiconductor circuit of the identificands may be derived from an external high-frequency source, in a manner already known. Alternatively, the current supply could be provided by a thermoelement heated by the identifier, or through a photosensitive solar cell. Finally, the current supply could be derived from the permanent data stroke received from the receiving coil or winding of the identificand, if the modulated interval is bridged by a small charging condenser.

The particular advantage of serial input and output is that only a small number of contact points or positions is needed. Another advantage is that the correlation field can be produced easily by a corresponding program control in the integrated circuit itself, and in such a manner that it differs from one identificand to another.

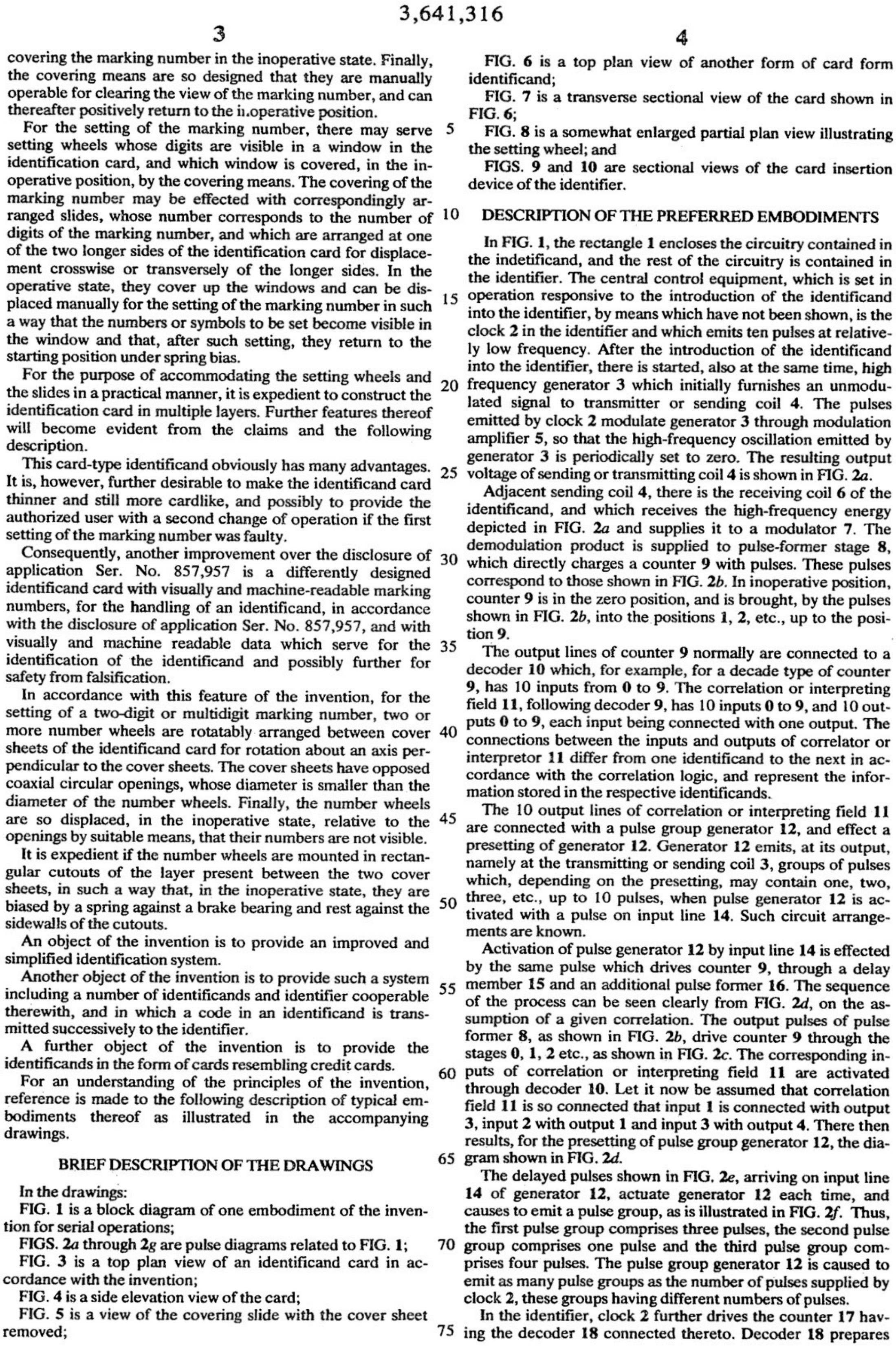
The present improvement over application Ser. No. 857,957 is not limited to the embodiments shown and described. In fact, combinations between the serial solution and the parallel solution are possible, for example, with serial input and parallel output or with parallel input and serial output, as well as arrangements for the input and output that are partly in parallel and partly in series.

The identificands and identifiers of application Ser. No. 857,957 comprise three novel technical features, namely, the correlation logic, the circuit for safety falsification, and the marking number in the identificands. Correlator circuits are known per se. Safety from falsification is attained in that there is provided, in the identificands, a component whose presence can be ascertained clearly by the identifier. This component is a specific integrated circuit, for the imitation of which very extensive manufacturing systems are necessary, so that falsification becomes unprofitable. Since the marking number is lodged in the identificand, rather than in the identifier as in known systems, spying out of the marking number is rendered impossible.

In application Ser. No. 857,957, the identificands are designed as small, key-type slides in which the above named three features are incorporated. In their mechanical construction, the identifiers correspond to this form of identificands. The carrying into effect of the principles mentioned above, however, is not limited to these forms of identificands or identifiers, but can be performed with numerous other forms. Thus, for example, identificands in the form of a pin of square cross section, or in the form which comes very close to the widely used "credit cards" and, at the same time, to arrange the identifiers for checking and for data transfer from these identificands. Accordingly, a further improvement over the disclosure of application Ser. No. 857,957 relates to a new identificand essentially in the form of a "credit card."

In accordance with this feature of the present invention, the identificand, which contains visually and machine-readable data serving for the identification of the identificand and for safety from falsification, is designed in card form. Additionally, there are provided devices for the selective setting of a two-digit or multidigit marking number, and means for

Figure B.203: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.



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covering the marking number in the inoperative state. Finally, the covering means are so designed that they are manually operable for clearing the view of the marking number, and can thereafter positively return to the inoperative position.

For the setting of the marking number, there may serve setting wheels whose digits are visible in a window in the identification card, and which window is covered, in the inoperative position, by the covering means. The covering of the marking number may be effected with correspondingly arranged slides, whose number corresponds to the number of digits of the marking number, and which are arranged at one of the two longer sides of the identification card for displacement crosswise or transversely of the longer sides. In the operative state, they cover up the windows and can be displaced manually for the setting of the marking number in such a way that the numbers or symbols to be set become visible in the window and that, after such setting, they return to the starting position under spring bias.

For the purpose of accommodating the setting wheels and the slides in a practical manner, it is expedient to construct the identification card in multiple layers. Further features thereof will become evident from the claims and the following description.

This card-type identificand obviously has many advantages. It is, however, further desirable to make the identificand card thinner and still more cardlike, and possibly to provide the authorized user with a second change of operation if the first setting of the marking number was faulty.

Consequently, another improvement over the disclosure of application Ser. No. 857,957 is a differently designed identificand card with visually and machine-readable marking numbers, for the handling of an identificand, in accordance with the disclosure of application Ser. No. 857,957, and with visually and machine readable data which serve for the identification of the identificand and possibly further for safety from falsification.

In accordance with this feature of the invention, for the setting of a two-digit or multidigit marking number, two or more number wheels are rotatably arranged between cover sheets of the identificand card for rotation about an axis perpendicular to the cover sheets. The cover sheets have opposed coaxial circular openings, whose diameter is smaller than the diameter of the number wheels. Finally, the number wheels are so displaced, in the inoperative state, relative to the openings by suitable means, that their numbers are not visible.

It is expedient if the number wheels are mounted in rectangular cutouts of the layer present between the two cover sheets, in such a way that, in the inoperative state, they are biased by a spring against a brake bearing and rest against the sidewalls of the cutouts.

An object of the invention is to provide an improved and simplified identification system.

Another object of the invention is to provide such a system including a number of identificands and identifier cooperable therewith, and in which a code in an identificand is transmitted successively to the identifier.

A further object of the invention is to provide the identificands in the form of cards resembling credit cards.

For an understanding of the principles of the invention, reference is made to the following description of typical embodiments thereof as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a block diagram of one embodiment of the invention for serial operations;

FIGS. **2***a* through **2***g* are pulse diagrams related to FIG. **1**;

FIG. **3** is a top plan view of an identificand card in accordance with the invention;

FIG. **4** is a side elevation view of the card;

FIG. **5** is a view of the covering slide with the cover sheet removed;

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FIG. **6** is a top plan view of another form of card form identificand;

FIG. **7** is a transverse sectional view of the card shown in FIG. **6**;

FIG. **8** is a somewhat enlarged partial plan view illustrating the setting wheel; and

FIGS. **9** and **10** are sectional views of the card insertion device of the identifier.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, the rectangle **1** encloses the circuitry contained in the indetificand, and the rest of the circuitry is contained in the identifier. The central control equipment, which is set in operation responsive to the introduction of the identificand into the identifier, by means which have not been shown, is the clock **2** in the identifier and which emits ten pulses at relatively low frequency. After the introduction of the identificand into the identifier, there is started, also at the same time, high frequency generator **3** which initially furnishes an unmodulated signal to transmitter or sending coil **4**. The pulses emitted by clock **2** modulate generator **3** through modulation amplifier **5**, so that the high-frequency oscillation emitted by generator **3** is periodically set to zero. The resulting output voltage of sending or transmitting coil **4** is shown in FIG. **2***a*.

Adjacent sending coil **4**, there is the receiving coil **6** of the identificand, and which receives the high-frequency energy depicted in FIG. **2***a* and supplies it to a modulator **7**. The demodulation product is supplied to pulse-former stage **8**, which directly charges a counter **9** with pulses. These pulses correspond to those shown in FIG. **2***b*. In inoperative position, counter **9** is in the zero position, and is brought, by the pulses shown in FIG. **2***b*, into the positions **1**, **2**, etc., up to the position **9**.

The output lines of counter **9** normally are connected to a decoder **10** which, for example, for a decade type of counter **9**, has 10 inputs from **0** to **9**. The correlation or interpreting field **11**, following decoder **9**, has 10 inputs **0** to **9**, and 10 outputs **0** to **9**, each input being connected with one output. The connections between the inputs and outputs of correlator or interpretor **11** differ from one identificand to the next in accordance with the correlation logic, and represent the information stored in the respective identificands.

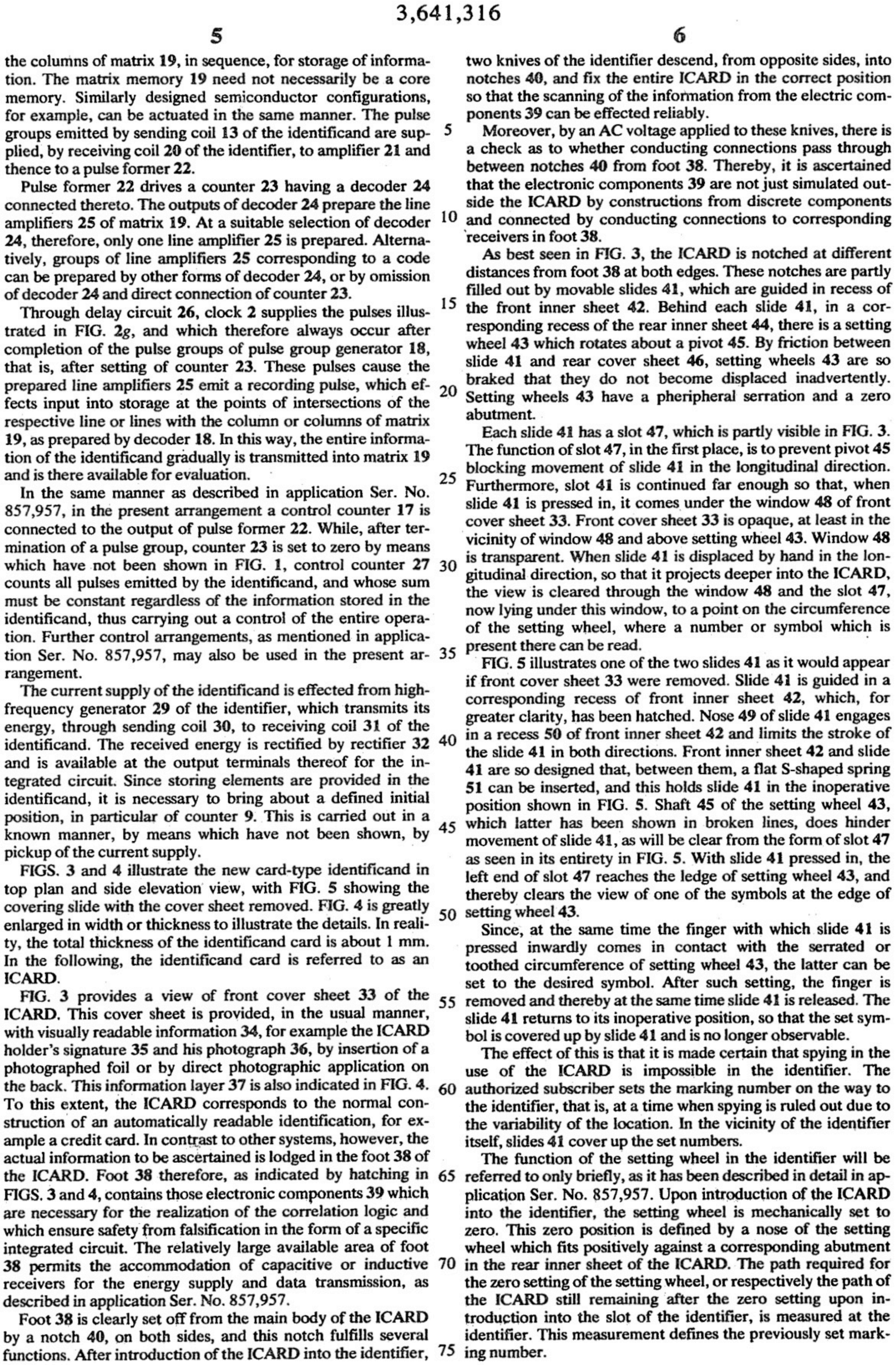
The 10 output lines of correlation or interpreting field **11** are connected with a pulse group generator **12**, and effect a presetting of generator **12**. Generator **12** emits, at its output, namely at the transmitting or sending coil **3**, groups of pulses which, depending on the presetting, may contain one, two, three, etc., up to 10 pulses, when pulse generator **12** is activated with a pulse on input line **14**. Such circuit arrangements are known.

Activation of pulse generator **12** by input line **14** is effected by the same pulse which drives counter **9**, through a delay member **15** and an additional pulse former **16**. The sequence of the process can be seen clearly from FIG. **2***d*, on the assumption of a given correlation. The output pulses of pulse former **8**, as shown in FIG. **2***b*, drive counter **9** through the stages **0**, **1**, **2** etc., as shown in FIG. **2***c*. The corresponding inputs of correlation or interpreting field **11** are activated through decoder **10**. Let it now be assumed that correlation field **11** is so connected that input **1** is connected with output **3**, input **2** with output **1** and input **3** with output **4**. There then results, for the presetting of pulse group generator **12**, the diagram shown in FIG. **2***d*.

The delayed pulses shown in FIG. **2***e*, arriving on input line **14** of generator **12**, actuate generator **12** each time, and causes to emit a pulse group, as is illustrated in FIG. **2***f*. Thus, the first pulse group comprises three pulses, the second pulse group comprises one pulse and the third pulse group comprises four pulses. The pulse group generator **12** is caused to emit as many pulse groups as the number of pulses supplied by clock **2**, these groups having different numbers of pulses.

In the identifier, clock **2** further drives the counter **17** having the decoder **18** connected thereto. Decoder **18** prepares

Figure B.204: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.



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the columns of matrix **19**, in sequence, for storage of information. The matrix memory **19** need not necessarily be a core memory. Similarly designed semiconductor configurations, for example, can be actuated in the same manner. The pulse groups emitted by sending coil **13** of the identificand are supplied, by receiving coil **20** of the identifier, to amplifier **21** and thence to a pulse former **22**.

Pulse former **22** drives a counter **23** having a decoder **24** connected thereto. The outputs of decoder **24** prepare the line amplifiers **25** of matrix **19**. At a suitable selection of decoder **24**, therefore, only one line amplifier **25** is prepared. Alternatively, groups of line amplifiers **25** corresponding to a code can be prepared by other forms of decoder **24**, or by omission of decoder **24** and direct connection of counter **23**.

Through delay circuit **26**, clock **2** supplies the pulses illustrated in FIG. **2***g*, and which therefore always occur after completion of the pulse groups of pulse group generator **18**, that is, after setting of counter **23**. These pulses cause the prepared line amplifiers **25** emit a recording pulse, which effects input into storage at the points of intersections of the respective line or lines with the column or columns of matrix **19**, as prepared by decoder **18**. In this way, the entire information of the identificand gradually is transmitted into matrix **19** and is there available for evaluation.

In the same manner as described in application Ser. No. 857,957, in the present arrangement a control counter **17** is connected to the output of pulse former **22**. While, after termination of a pulse group, counter **23** is set to zero by means which have not been shown in FIG. **1**, control counter **27** counts all pulses emitted by the identificand, and whose sum must be constant regardless of the information stored in the identificand, thus carrying out a control of the entire operation. Further control arrangements, as mentioned in application Ser. No. 857,957, may also be used in the present arrangement.

The current supply of the identificand is effected from high-frequency generator **29** of the identifier, which transmits its energy, through sending coil **30**, to receiving coil **31** of the identificand. The received energy is rectified by rectifier **32** and is available at the output terminals thereof for the integrated circuit. Since storing elements are provided in the identificand, it is necessary to bring about a defined initial position, in particular of counter **9**. This is carried out in a known manner, by means which have not been shown, by pickup of the current supply.

FIGS. **3** and **4** illustrate the new card-type identificand in top plan and side elevation view, with FIG. **5** showing the covering slide with the cover sheet removed. FIG. **4** is greatly enlarged in width or thickness to illustrate the details. In reality, the total thickness of the identificand card is about 1 mm. In the following, the identificand card is referred to as an ICARD.

FIG. **3** provides a view of front cover sheet **33** of the ICARD. This cover sheet is provided, in the usual manner, with visually readable information **34**, for example the ICARD holder's signature **35** and his photograph **36**, by insertion of a photographed foil or by direct photographic application on the back. This information layer **37** is also indicated in FIG. **4**. To this extent, the ICARD corresponds to the normal construction of an automatically readable identification, for example a credit card. In contrast to other systems, however, the actual information to be ascertained is lodged in the foot **38** of the ICARD. Foot **38** therefore, as indicated by hatching in FIGS. **3** and **4**, contains those electronic components **39** which are necessary for the realization of the correlation logic and which ensure safety from falsification in the form of a specific integrated circuit. The relatively large available area of foot **38** permits the accommodation of capacitive or inductive receivers for the energy supply and data transmission, as described in application Ser. No. 857,957.

Foot **38** is clearly set off from the main body of the ICARD by a notch **40**, on both sides, and this notch fulfills several functions. After introduction of the ICARD into the identifier, two knives of the identifier descend, from opposite sides, into notches **40**, and fix the entire ICARD in the correct position so that the scanning of the information from the electric components **39** can be effected reliably.

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Moreover, by an AC voltage applied to these knives, there is a check as to whether conducting connections pass through between notches **40** from foot **38**. Thereby, it is ascertained that the electronic components **39** are not just simulated outside the ICARD by constructions from discrete components and connected by conducting connections to corresponding receivers in foot **38**.

As best seen in FIG. **3**, the ICARD is notched at different distances from foot **38** at both edges. These notches are partly filled out by movable slides **41**, which are guided in recess of the front inner sheet **42**. Behind each slide **41**, in a corresponding recess of the rear inner sheet **44**, there is a setting wheel **43** which rotates about a pivot **45**. By friction between slide **41** and rear cover sheet **46**, setting wheels **43** are so braked that they do not become displaced inadvertently. Setting wheels **43** have a pheripheral serration and a zero abutment.

Each slide **41** has a slot **47**, which is partly visible in FIG. **3**. The function of slot **47**, in the first place, is to prevent pivot **45** blocking movement of slide **41** in the longitudinal direction. Furthermore, slot **41** is continued far enough so that, when slide **41** is pressed in, it comes under the window **48** of front cover sheet **33**. Front cover sheet **33** is opaque, at least in the vicinity of window **48** and above setting wheel **43**. Window **48** is transparent. When slide **41** is displaced by hand in the longitudinal direction, so that it projects deeper into the ICARD, the view is cleared through the window **48** and the slot **47**, now lying under this window, to a point on the circumference of the setting wheel, where a number or symbol which is present there can be read.

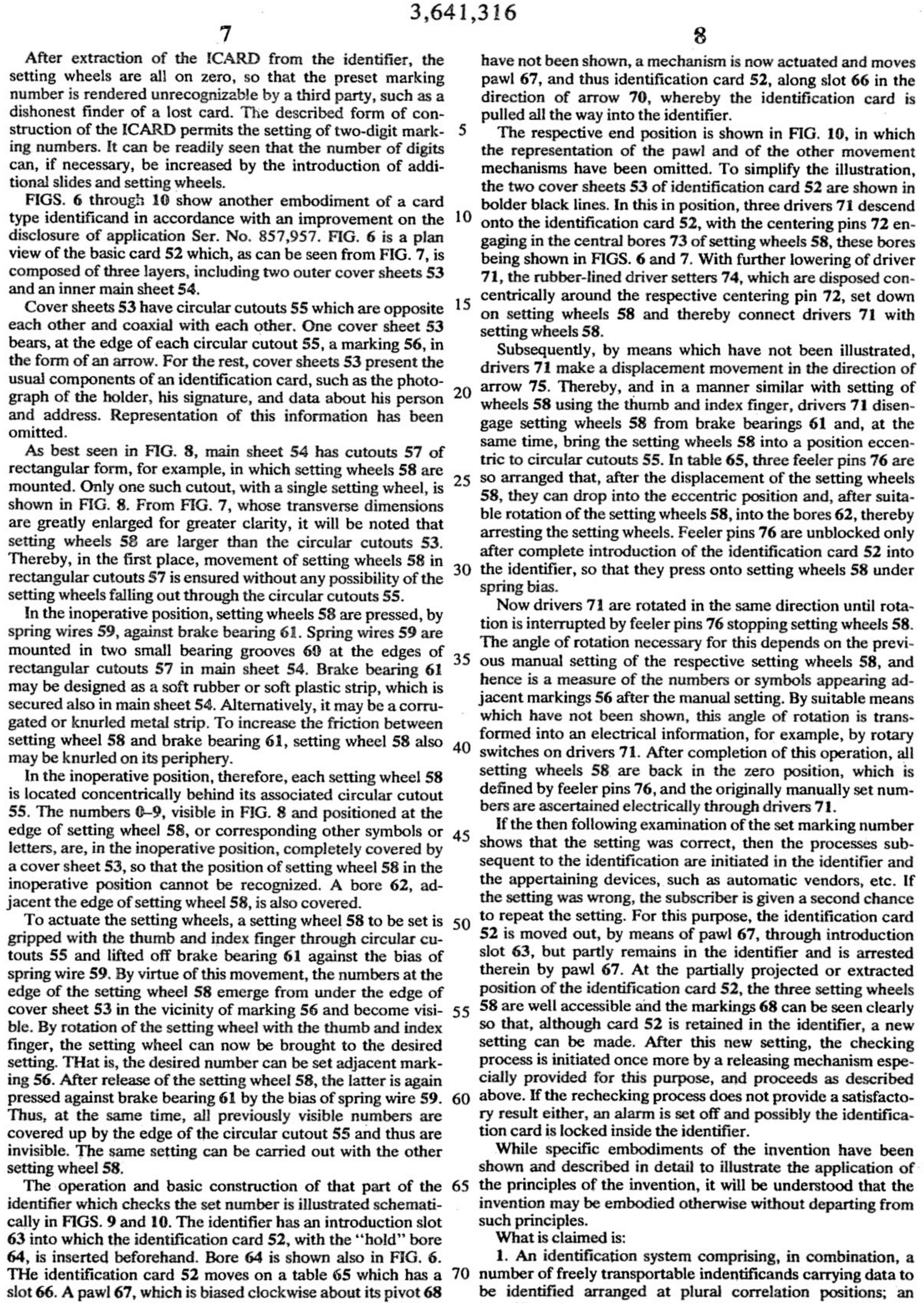
FIG. **5** illustrates one of the two slides **41** as it would appear if front cover sheet **33** were removed. Slide **41** is guided in a corresponding recess of front inner sheet **42**, which, for greater clarity, has been hatched. Nose **49** of slide **41** engages in a recess **50** of front inner sheet **42** and limits the stroke of the slide **41** in both directions. Front inner sheet **42** and slide **41** are so designed that, between them, a flat S-shaped spring **51** can be inserted, and this holds slide **41** in the inoperative position shown in FIG. **5**. Shaft **45** of the setting wheel **43**, which latter has been shown in broken lines, does hinder movement of slide **41**, as will be clear from the form of slot **47** as seen in its entirety in FIG. **5**. With slide **41** pressed in, the left end of slot **47** reaches the ledge of setting wheel **43**, and thereby clears the view of one of the symbols at the edge of setting wheel **43**.

Since, at the same time the finger with which slide **41** is pressed inwardly comes in contact with the serrated or toothed circumference of setting wheel **43**, the latter can be set to the desired symbol. After such setting, the finger is removed and thereby at the same time slide **41** is released. The slide **41** returns to its inoperative position, so that the set symbol is covered up by slide **41** and is no longer observable.

The effect of this is that it is made certain that spying in the use of the ICARD is impossible in the identifier. The authorized subscriber sets the marking number on the way to the identifier, that is, at a time when spying is ruled out due to the variability of the location. In the vicinity of the identifier itself, slides **41** cover up the set numbers.

The function of the setting wheel in the identifier will be referred to only briefly, as it has been described in detail in application Ser. No. 857,957. Upon introduction of the ICARD into the identifier, the setting wheel is mechanically set to zero. This zero position is defined by a nose of the setting wheel which fits positively against a corresponding abutment in the rear inner sheet of the ICARD. The path required for the zero setting of the setting wheel, or respectively the path of the ICARD still remaining after the zero setting upon introduction into the slot of the identifier, is measured at the identifier. This measurement defines the previously set marking number.

Figure B.205: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.



After extraction of the ICARD from the identifier, the setting wheels are all on zero, so that the preset marking number is rendered unrecognizable by a third party, such as a dishonest finder of a lost card. The described form of construction of the ICARD permits the setting of two-digit marking numbers. It can be readily seen that the number of digits can, if necessary, be increased by the introduction of additional slides and setting wheels.

FIGS. **6** through **10** show another embodiment of a card type identificand in accordance with an improvement on the disclosure of application Ser. No. 857,957. FIG. **6** is a plan view of the basic card **52** which, as can be seen from FIG. **7**, is composed of three layers, including two outer cover sheets **53** and an inner main sheet **54**.

Cover sheets **53** have circular cutouts **55** which are opposite each other and coaxial with each other. One cover sheet **53** bears, at the edge of each circular cutout **55**, a marking **56**, in the form of an arrow. For the rest, cover sheets **53** present the usual components of an identification card, such as the photograph of the holder, his signature, and data about his person and address. Representation of this information has been omitted.

As best seen in FIG. **8**, main sheet **54** has cutouts **57** of rectangular form, for example, in which setting wheels **58** are mounted. Only one such cutout, with a single setting wheel, is shown in FIG. **8**. From FIG. **7**, whose transverse dimensions are greatly enlarged for greater clarity, it will be noted that setting wheels **58** are larger than the circular cutouts **53**. Thereby, in the first place, movement of setting wheels **58** in rectangular cutouts **57** is ensured without any possibility of the setting wheels falling out through the circular cutouts **55**.

In the inoperative position, setting wheels **58** are pressed, by spring wires **59**, against brake bearing **61**. Spring wires **59** are mounted in two small bearing grooves **60** at the edges of rectangular cutouts **57** in main sheet **54**. Brake bearing **61** may be designed as a soft rubber or soft plastic strip, which is secured also in main sheet **54**. Alternatively, it may be a corrugated or knurled metal strip. To increase the friction between setting wheel **58** and brake bearing **61**, setting wheel **58** also may be knurled on its periphery.

In the inoperative position, therefore, each setting wheel **58** is located concentrically behind its associated circular cutout **55**. The numbers **0–9**, visible in FIG. **8** and positioned at the edge of setting wheel **58**, or corresponding other symbols or letters, are, in the inoperative position, completely covered by a cover sheet **53**, so that the position of setting wheel **58** in the inoperative position cannot be recognized. A bore **62**, adjacent the edge of setting wheel **58**, is also covered.

To actuate the setting wheels, a setting wheel **58** to be set is gripped with the thumb and index finger through circular cutouts **55** and lifted off brake bearing **61** against the bias of spring wire **59**. By virtue of this movement, the numbers at the edge of the setting wheel **58** emerge from under the edge of cover sheet **53** in the vicinity of marking **56** and become visible. By rotation of the setting wheel with the thumb and index finger, the setting wheel can now be brought to the desired setting. THat is, the desired number can be set adjacent marking **56**. After release of the setting wheel **58**, the latter is again pressed against brake bearing **61** by the bias of spring wire **59**. Thus, at the same time, all previously visible numbers are covered up by the edge of the circular cutout **55** and thus are invisible. The same setting can be carried out with the other setting wheel **58**.

The operation and basic construction of that part of the identifier which checks the set number is illustrated schematically in FIGS. **9** and **10**. The identifier has an introduction slot **63** into which the identification card **52**, with the "hold" bore **64**, is inserted beforehand. Bore **64** is shown also in FIG. **6**. THe identification card **52** moves on a table **65** which has a slot **66**. A pawl **67**, which is biased clockwise about its pivot **68** in the direction of arrow **69** by a spring which has not been shown, moves in slot **66**. Upon introduction of an identification card **52** into slot **63**, pawl **67** is, at first, pressed down until it can drop into "hold" bore **64**. By pressure switches, which have not been shown, a mechanism is now actuated and moves pawl **67**, and thus identification card **52**, along slot **66** in the direction of arrow **70**, whereby the identification card is pulled all the way into the identifier.

The respective end position is shown in FIG. **10**, in which the representation of the pawl and of the other movement mechanisms have been omitted. To simplify the illustration, the two cover sheets **53** of identification card **52** are shown in bolder black lines. In this in position, three drivers **71** descend onto the identification card **52**, with the centering pins **72** engaging in the central bores **73** of setting wheels **58**, these bores being shown in FIGS. **6** and **7**. With further lowering of driver **71**, the rubber-lined driver setters **74**, which are disposed concentrically around the respective centering pin **72**, set down on setting wheels **58** and thereby connect drivers **71** with setting wheels **58**.

Subsequently, by means which have not been illustrated, drivers **71** make a displacement movement in the direction of arrow **75**. Thereby, and in a manner similar with setting of wheels **58** using the thumb and index finger, drivers **71** disengage setting wheels **58** from brake bearings **61** and, at the same time, bring the setting wheels **58** into a position eccentric to circular cutouts **55**. In table **65**, three feeler pins **76** are so arranged that, after the displacement of the setting wheels **58**, they can drop into the eccentric position and, after suitable rotation of the setting wheels **58**, into the bores **62**, thereby arresting the setting wheels. Feeler pins **76** are unblocked only after complete introduction of the identification card **52** into the identifier, so that they press onto setting wheels **58** under spring bias.

Now drivers **71** are rotated in the same direction until rotation is interrupted by feeler pins **76** stopping setting wheels **58**. The angle of rotation necessary for this depends on the previous manual setting of the respective setting wheels **58**, and hence is a measure of the numbers or symbols appearing adjacent markings **56** after the manual setting. By suitable means which have not been shown, this angle of rotation is transformed into an electrical information, for example, by rotary switches on drivers **71**. After completion of this operation, all setting wheels **58** are back in the zero position, which is defined by feeler pins **76**, and the originally manually set numbers are ascertained electrically through drivers **71**.

If the then following examination of the set marking number shows that the setting was correct, then the processes subsequent to the identification are initiated in the identifier and the appertaining devices, such as automatic vendors, etc. If the setting was wrong, the subscriber is given a second chance to repeat the setting. For this purpose, the identification card **52** is moved out, by means of pawl **67**, through introduction slot **63**, but partly remains in the identifier and is arrested therein by pawl **67**. At the partially projected or extracted position of the identification card **52**, the three setting wheels **58** are well accessible and the markings **68** can be seen clearly so that, although card **52** is retained in the identifier, a new setting can be made. After this new setting, the checking process is initiated once more by a releasing mechanism especially provided for this purpose, and proceeds as described above. If the rechecking process does not provide a satisfactory result either, an alarm is set off and possibly the identification card is locked inside the identifier.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. An identification system comprising, in combination, a number of freely transportable indentificands carrying data to be identified arranged at plural correlation positions; an identifier cooperable with said identificands to check the identity of a user thereof; a first transmitter in said identifier transmitting, to an identificand inserted into said identifier, a number of data, corresponding to the number of correlation

Figure B.206: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

positions of the inserted identificand, in sequence from successive correlation positions a respective interpreter in each identificand, having input and output terminals; a respective selector device in each identificand supplying the data, transmitted by said transmitter, to the input terminals of the associated interpreter; and a respective second transmitter in each identificand connected to the output terminals of the associated interpreter to have applied thereto modulations determined by said associated interpreter; each second transmitter transmitting the resultant modulated signals to said identifier for processing.

2. An identification system, as claimed in claim **1**, including a receiver in said identifier; a clock in said identifier emitting periodic pulses when activated; the input terminals of the interpreter of an inserted identificand being marked successively in the rhythm of the clock pulses of the identifier; a respective pulse group generator in each identificand connected to the output terminals of the associated interpreter, and present in accordance with each marked output to emit a pulse number fixedly correlated with the respective output; said pulse group generator transmitting the thus successively occurring pulse groups to said identifier, in the rhythm of the clock pulses, for storing for evaluation.

3. An identification system, as claimed in claim **2**, including a respective counter in each identificand; the counter of an inserted identifier being advanced by said clock pulses and successively marking the input terminals of the associated interpreter; the marked output terminals of the associated interpreter effecting presetting of the associated pulse group generator which, in turn, is switched on by said clock pulses.

4. An identification system, as claimed in claim **3**, in which the pulses transmitted from said identifier, actuated said counter directly, and actuate the pulse group generator of an inserted identificand through a respective delay circuit.

5. An identification system, as claimed in claim **1**, including a matrix memory in said identifier having two sets of intersecting coordinates defining a grid; one set of coordinates being marked successively in the rhythm of said clock pulses and the other set of coordinates being marked by the pulse groups emitted by the inserted identificand.

6. An identification system, as claimed in claim **5**, including a second counter in said identifier counting the pulses transmitted by the inserted identificand; and a decoder connected to said second counter and to said matrix memory and marking said other set of coordinates thereof.

7. An identification system, as claimed in claim **1**, and including a respective presettable pulse generator in each identificand connected to the associated interpreter and, in accordance with the marking of the output terminals of the associated interpreter, generating pulses of different lengths which are evaluated in said identifier.

8. An identification system, as claimed in claim **1**, in which said first transmitter successively sends different frequencies to the inserted identificand; the input terminals of the respective interpreter of each identificand consisting of frequency-selective filters which filter out the frequencies successively arriving thereat through a common input line; said interpreter effecting a rearrangement of the frequency sequence.

9. An identification system, as claimed in claim **8**, in which said first transmitter successively sends different frequency combinations to the inserted identificand.

10. An identification system, as claimed in claim **1**, including respective integrated circuits in each identificand simultaneously serving for safety from falsification of the associated identificand.

11. An identification system, as claimed in claim **1**, in which transmission of pulses between said identifier and the inserted identificand is effected inductively.

12. An identification system as claimed in claim **1**, in which transmission of pulses between said identifier and the inserted identificand is effected capacitively.

13. An identification system, as claimed in claim **1**, in which transmission of pulses between said identifier and the inserted identificand is effected optically.

14. An identification system, as claimed in claim **1**, in which current is supplied to the inserted identificand by transmission from a high-frequency generator in said identifier to a receiver in the inserted identificand.

15. An identification system, as claimed in claim **1**, in which current is supplied to the inserted identificand from a thermoelement.

16. An identification system, as claimed in claim **1**, in which current is supplied to the inserted identificand from a solar cell.

17. An identification system, as claimed in claim **1**, in which current is supplied to the inserted identificand by a high-frequency transmitter in said identifier and an associated charger condenser.

18. For use in an identification system, as claimed in claim **1**, an identificand with a visual and machine readable marking number and in the form of a card carrying visually and machine readable data serving for the identification of the identificand and for safety from falsification; said identificand including devices operable to selectively set a multidigit marking number; means covering the marking number in the inoperative state of the identificand; said covering means being constructed and arranged for manual operation to expose the marking number for setting of said devices; and means positively returning said covering means to the inoperative position.

19. An identification system, as claimed in claim **18**, in which said devices for selectively setting a multidigit marking number comprise setting wheels carrying numbers visible in a window in said identificand; said window being covered by said covering means in the inoperative state.

20. An identification system, as claimed in claim **19**, in which said identificand card has two longer sides; at least one of said longer sides supporting a number of slides corresponding to the number of digits of said marking number, said slides being displaceable transversely of said longer sides and, in the inoperative state, covering associated windows; said slides being manually displaceable, for setting of the marking number, to a position in which the numbers to be set are visible in the associated windows.

21. An identification system, as claimed in claim **20**, in which said identificand card is constructed in multiple layers; said setting wheels and said slides being positioned between layers of said identificand card.

22. An identification system, as claimed in claim **18**, in which said identificand card has a narrow end; and correlation logic and means providing safety from falsification positioned in said narrow end.

23. An identification system, as claimed in claim **22**, including energy supply means and the means for data transmission positioned in said narrow end.

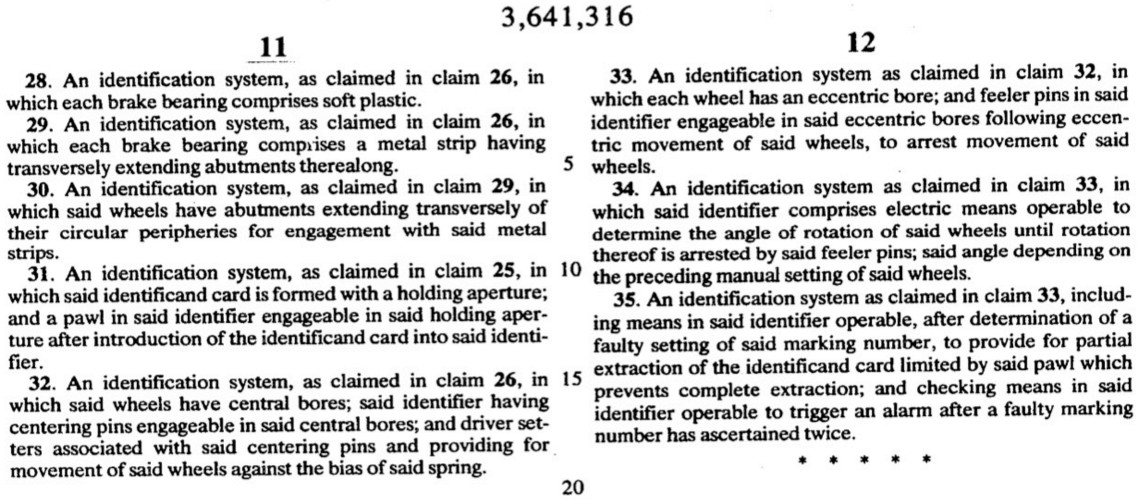
24. An identification system, as claimed in claim **22**, in which said narrow end has notches serving for correct fixation of said identificand card in said identifier.

25. An identification system as claimed in claim **1**, including an identificand with visually and machine-readable marking numbers, designed in the form of a card and containing visually and machine-readable data serving to identify the identificand and for safety from falsification; said identificand card comprising cover sheets; at least two wheels rotatably positioned between said cover sheets for setting a multidigit marking number; said cover sheets having opposite coaxial circular openings whose diameter is smaller than the diameter of said wheels; and means biasing said wheels relative to said circular openings, in the inoperative state, so that the numbers on said wheels are not visible.

26. An identification system, as claimed in claim **25**, in which said identificand includes an intermediate layer between said cover sheets and formed with rectangular cutouts; said wheels being mounted in said rectangular cutouts; and respective spring means seating against the side edges of said cutouts and biasing the associate wheels into engagement with the respective brake bearings.

27. An identification system, as claimed in claim **26**, in which each brake bearing comprises soft rubber.

Figure B.207: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.



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28. An identification system, as claimed in claim **26**, in which each brake bearing comprises soft plastic.

29. An identification system, as claimed in claim **26**, in which each brake bearing comprises a metal strip having transversely extending abutments therealong.

30. An identification system, as claimed in claim **29**, in which said wheels have abutments extending transversely of their circular peripheries for engagement with said metal strips.

31. An identification system, as claimed in claim **25**, in which said identificand card is formed with a holding aperture; and a pawl in said identifier engageable in said holding aperture after introduction of the identificand card into said identifier.

32. An identification system, as claimed in claim **26**, in which said wheels have central bores; said identifier having centering pins engageable in said central bores; and driver setters associated with said centering pins and providing for movement of said wheels against the bias of said spring.

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33. An identification system as claimed in claim **32**, in which each wheel has an eccentric bore; and feeler pins in said identifier engageable in said eccentric bores following eccentric movement of said wheels, to arrest movement of said wheels.

34. An identification system as claimed in claim **33**, in which said identifier comprises electric means operable to determine the angle of rotation of said wheels until rotation thereof is arrested by said feeler pins; said angle depending on the preceding manual setting of said wheels.

35. An identification system as claimed in claim **33**, including means in said identifier operable, after determination of a faulty setting of said marking number, to provide for partial extraction of the identificand card limited by said pawl which prevents complete extraction; and checking means in said identifier operable to trigger an alarm after a faulty marking number has ascertained twice.

* * * * *

Figure B.208: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966. Earlier, Gröttrup developed avionics systems in Germany during the war and led the German-speaking contributions to the postwar Soviet ballistic missile program.

B.4 Light Emitting Diodes (LEDs) and Laser Diodes

[German-speaking scientists played leading roles in the development of light emitting diodes (LEDs) and laser diodes. LEDs are much more energy-efficient than incandescent and even fluorescent bulbs, so they are now widely used for everything from illuminated video screens to room lighting. Laser diodes are more compact, rugged, and efficient than most other types of lasers, so they are used for everything from optical disc drives to laser pointers. Both LEDs and laser diodes are utilized in different types of bar code scanners.

Bernhard Gudden (German, 1892–1945) and Robert Pohl (German, 1884–1976) developed and demonstrated the first electroluminescent semiconductor devices, the forerunners of LEDs, during the period 1919–1923 [*Zeitschrift für Physik* 18:1:199–206 (1923)]. They also developed improved photoelectric cells. See pp. 1106 and 2889.

Zoltan Bay (Hungarian, 1900–1992) and György Szigeti (Hungarian, 1905–1978) extended the work of Gudden and Pohl and filed patent applications on true LEDs in 1939, as shown on pp. 2890–2894.

Kurt Lehovec (Bohemian/Austrian/Czech, 1918–2012) worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs, quite possibly based on wartime work. See pp. 1097, 2757–2759, and 2895–2910.

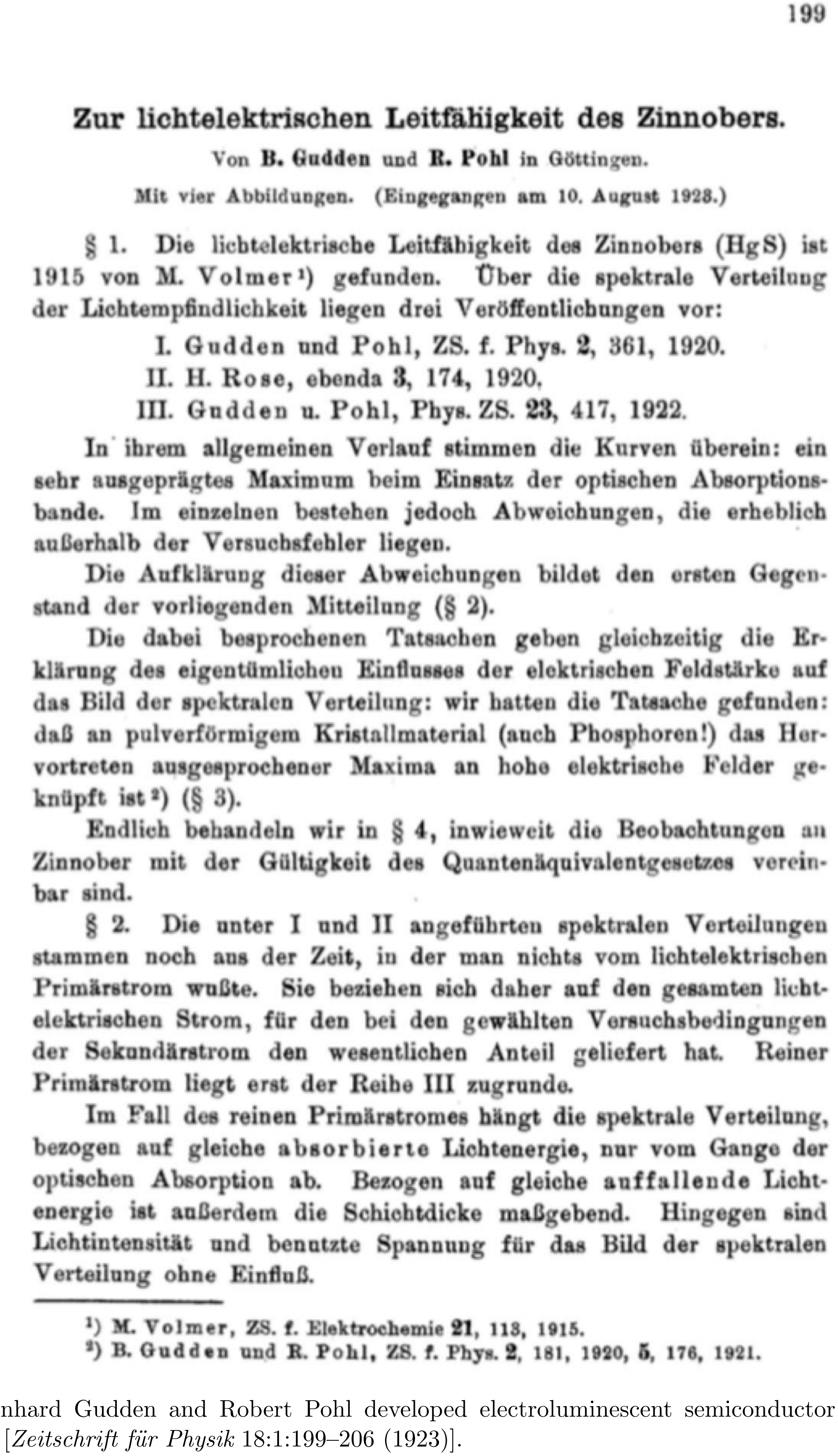
John von Neumann (Hungarian, 1903–1957) made a detailed proposal for laser diodes in 1953, which was likely circulated via his many consulting roles in government and industry, and therefore had a broad and profound influence [*IEEE Journal of Quantum Electronics* 23:6:659–673 (1987)]. See p. 2911.

Walter Heywang (German, 1923–2010) filed detailed patent applications on laser diodes in 1958 (pp. 2912–2916)

Herbert Kroemer (German, 1928–) filed patent applications on the double-heterostructure laser diode in 1963 (pp. 2917–2922). He also invented the drift transistor in 1953 and III-V semiconductor heterostructures in 1966. Kroemer won the Nobel Prize in Physics in 2000 for his innovations in microelectronics (p. 1104).

Other groups produced various types of laser diodes around the same time as Heywang and Kroemer. More archival research is needed to determine whether work in the other laser diode groups was seeded by Heywang's or Kroemer's ideas prior to their formal patent applications, by von Neumann's 1953 proposal, or by other German-speaking work going back to World War II.]

Bernhard Gudden (1892–1945) and Robert Pohl (1884–1976) developed electroluminescent semiconductor devices (1919–1923) [*Zeitschrift für Physik* 18:1:199–206 (1923)]



Zur lichtelektrischen Leitfähigkeit des Zinnobers.

Von **B. Gudden** und **R. Pohl** in Göttingen.

Mit vier Abbildungen. (Eingegangen am 10. August 1923.)

§ 1. Die lichtelektrische Leitfähigkeit des Zinnobers (HgS) ist 1915 von M. Volmer[1]) gefunden. Über die spektrale Verteilung der Lichtempfindlichkeit liegen drei Veröffentlichungen vor:

I. Gudden und Pohl, ZS. f. Phys. **2**, 361, 1920.
II. H. Rose, ebenda **3**, 174, 1920.
III. Gudden u. Pohl, Phys. ZS. **23**, 417, 1922.

In ihrem allgemeinen Verlauf stimmen die Kurven überein: ein sehr ausgeprägtes Maximum beim Einsatz der optischen Absorptionsbande. Im einzelnen bestehen jedoch Abweichungen, die erheblich außerhalb der Versuchsfehler liegen.

Die Aufklärung dieser Abweichungen bildet den ersten Gegenstand der vorliegenden Mitteilung (§ 2).

Die dabei besprochenen Tatsachen geben gleichzeitig die Erklärung des eigentümlichen Einflusses der elektrischen Feldstärke auf das Bild der spektralen Verteilung: wir hatten die Tatsache gefunden: daß an pulverförmigem Kristallmaterial (auch Phosphoren!) das Hervortreten ausgesprochener Maxima an hohe elektrische Felder geknüpft ist[2]) (§ 3).

Endlich behandeln wir in § 4, inwieweit die Beobachtungen an Zinnober mit der Gültigkeit des Quantenäquivalentgesetzes vereinbar sind.

§ 2. Die unter I und II angeführten spektralen Verteilungen stammen noch aus der Zeit, in der man nichts vom lichtelektrischen Primärstrom wußte. Sie beziehen sich daher auf den gesamten lichtelektrischen Strom, für den bei den gewählten Versuchsbedingungen der Sekundärstrom den wesentlichen Anteil geliefert hat. Reiner Primärstrom liegt erst der Reihe III zugrunde.

Im Fall des reinen Primärstromes hängt die spektrale Verteilung, bezogen auf gleiche absorbierte Lichtenergie, nur vom Gange der optischen Absorption ab. Bezogen auf gleiche auffallende Lichtenergie ist außerdem die Schichtdicke maßgebend. Hingegen sind Lichtintensität und benutzte Spannung für das Bild der spektralen Verteilung ohne Einfluß.

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[1]) M. Volmer, ZS. f. Elektrochemie **21**, 113, 1915.
[2]) B. Gudden und R. Pohl, ZS. f. Phys. **2**, 181, 1920, **5**, 176, 1921.

Figure B.209: Bernhard Gudden and Robert Pohl developed electroluminescent semiconductor devices 1919–1923 [*Zeitschrift für Physik* 18:1:199–206 (1923)].

Sept. 2, 1941. Z. BAY ET AL **2,254,957**

ELECTRIC SOURCE OF LIGHT

Filed Nov. 12, 1940

Fig. 1.

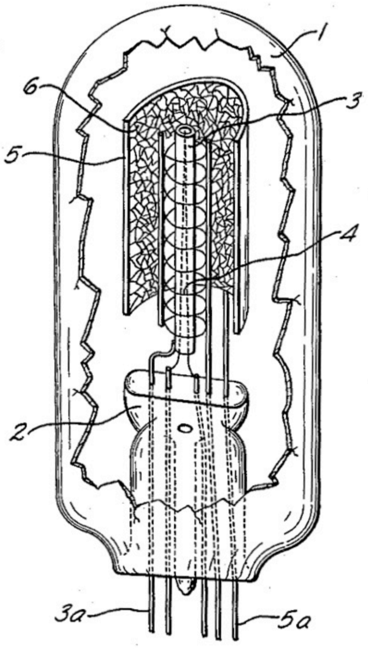


Fig. 2.

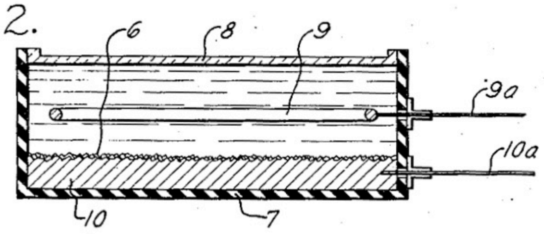
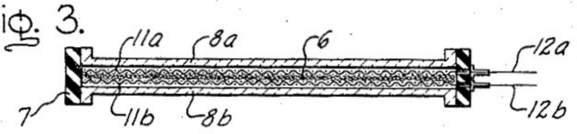
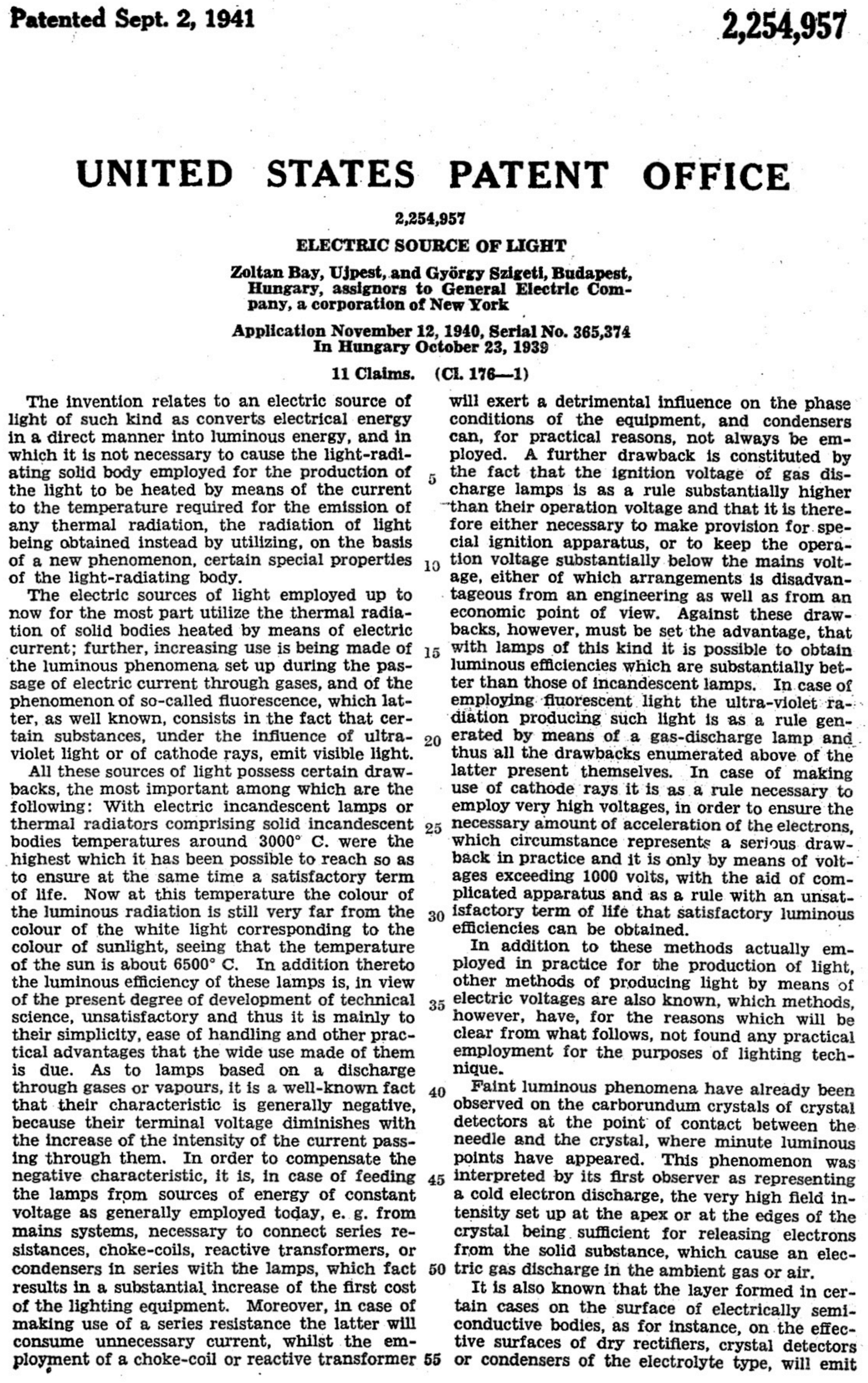


Fig. 3.



Inventors
Zoltan Bay
György Szigeti
by John H. Anderson
Their Attorney

Figure B.210: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.



Patented Sept. 2, 1941 **2,254,957**

UNITED STATES PATENT OFFICE

2,254,957

ELECTRIC SOURCE OF LIGHT

Zoltan Bay, Ujpest, and György Szigeti, Budapest, Hungary, assignors to General Electric Company, a corporation of New York

Application November 12, 1940, Serial No. 365,374
In Hungary October 23, 1939

11 Claims. (Cl. 176—1)

The invention relates to an electric source of light of such kind as converts electrical energy in a direct manner into luminous energy, and in which it is not necessary to cause the light-radiating solid body employed for the production of the light to be heated by means of the current to the temperature required for the emission of any thermal radiation, the radiation of light being obtained instead by utilizing, on the basis of a new phenomenon, certain special properties of the light-radiating body.

The electric sources of light employed up to now for the most part utilize the thermal radiation of solid bodies heated by means of electric current; further, increasing use is being made of the luminous phenomena set up during the passage of electric current through gases, and of the phenomenon of so-called fluorescence, which latter, as well known, consists in the fact that certain substances, under the influence of ultra-violet light or of cathode rays, emit visible light.

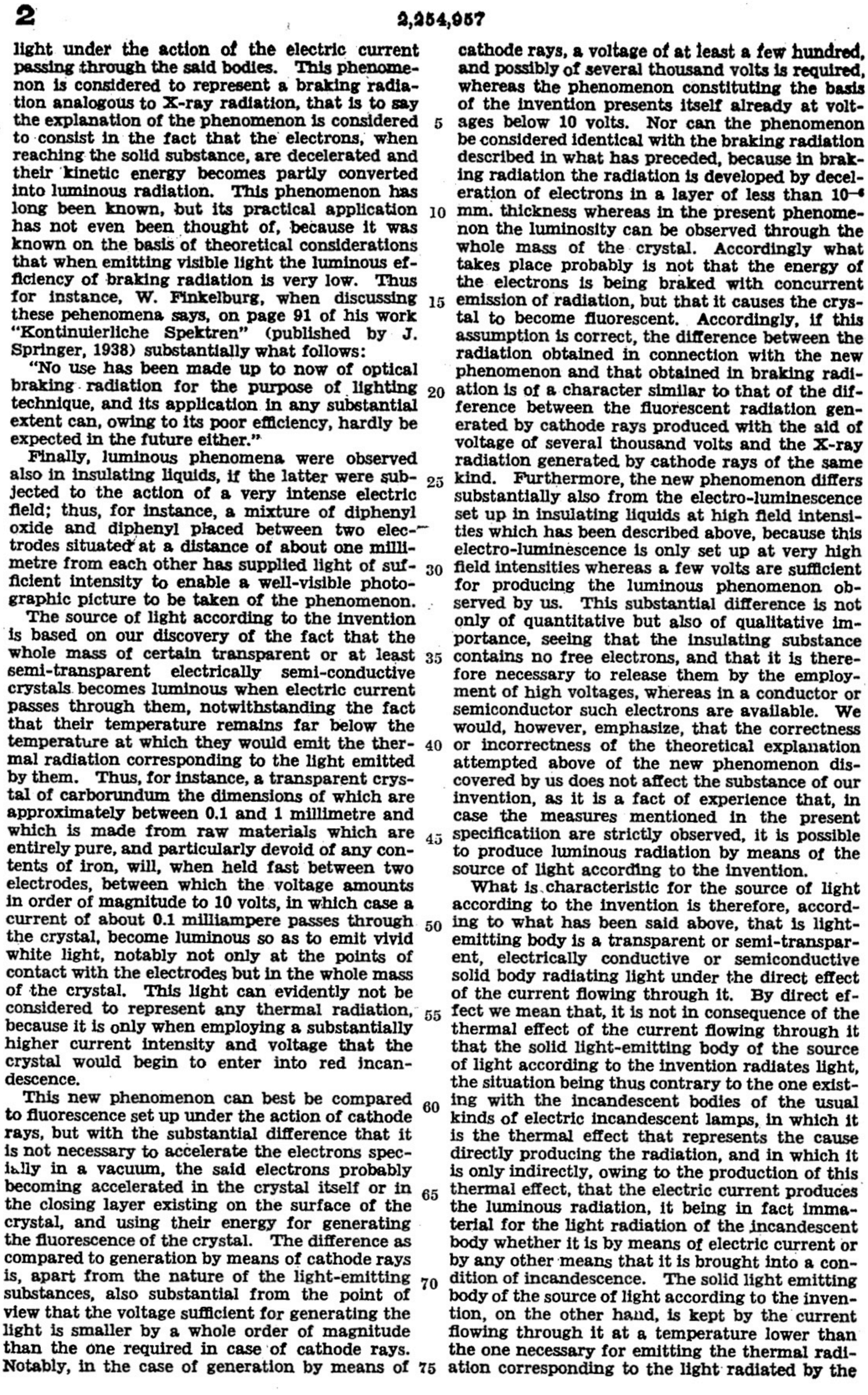
All these sources of light possess certain drawbacks, the most important among which are the following: With electric incandescent lamps or thermal radiators comprising solid incandescent bodies temperatures around 3000° C. were the highest which it has been possible to reach so as to ensure at the same time a satisfactory term of life. Now at this temperature the colour of the luminous radiation is still very far from the colour of the white light corresponding to the colour of sunlight, seeing that the temperature of the sun is about 6500° C. In addition thereto the luminous efficiency of these lamps is, in view of the present degree of development of technical science, unsatisfactory and thus it is mainly to their simplicity, ease of handling and other practical advantages that the wide use made of them is due. As to lamps based on a discharge through gases or vapours, it is a well-known fact that their characteristic is generally negative, because their terminal voltage diminishes with the increase of the intensity of the current passing through them. In order to compensate the negative characteristic, it is, in case of feeding the lamps from sources of energy of constant voltage as generally employed today, e. g. from mains systems, necessary to connect series resistances, choke-coils, reactive transformers, or condensers in series with the lamps, which fact results in a substantial increase of the first cost of the lighting equipment. Moreover, in case of making use of a series resistance the latter will consume unnecessary current, whilst the employment of a choke-coil or reactive transformer will exert a detrimental influence on the phase conditions of the equipment, and condensers can, for practical reasons, not always be employed. A further drawback is constituted by the fact that the ignition voltage of gas discharge lamps is as a rule substantially higher than their operation voltage and that it is therefore either necessary to make provision for special ignition apparatus, or to keep the operation voltage substantially below the mains voltage, either of which arrangements is disadvantageous from an engineering as well as from an economic point of view. Against these drawbacks, however, must be set the advantage, that with lamps of this kind it is possible to obtain luminous efficiencies which are substantially better than those of incandescent lamps. In case of employing fluorescent light the ultra-violet radiation producing such light is as a rule generated by means of a gas-discharge lamp and thus all the drawbacks enumerated above of the latter present themselves. In case of making use of cathode rays it is as a rule necessary to employ very high voltages, in order to ensure the necessary amount of acceleration of the electrons, which circumstance represents a serious drawback in practice and it is only by means of voltages exceeding 1000 volts, with the aid of complicated apparatus and as a rule with an unsatisfactory term of life that satisfactory luminous efficiencies can be obtained.

In addition to these methods actually employed in practice for the production of light, other methods of producing light by means of electric voltages are also known, which methods, however, have, for the reasons which will be clear from what follows, not found any practical employment for the purposes of lighting technique.

Faint luminous phenomena have already been observed on the carborundum crystals of crystal detectors at the point of contact between the needle and the crystal, where minute luminous points have appeared. This phenomenon was interpreted by its first observer as representing a cold electron discharge, the very high field intensity set up at the apex or at the edges of the crystal being sufficient for releasing electrons from the solid substance, which cause an electric gas discharge in the ambient gas or air.

It is also known that the layer formed in certain cases on the surface of electrically semiconductive bodies, as for instance, on the effective surfaces of dry rectifiers, crystal detectors or condensers of the electrolyte type, will emit

Figure B.211: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.



2 **2,254,957**

light under the action of the electric current passing through the said bodies. This phenomenon is considered to represent a braking radiation analogous to X-ray radiation, that is to say the explanation of the phenomenon is considered to consist in the fact that the electrons, when reaching the solid substance, are decelerated and their kinetic energy becomes partly converted into luminous radiation. This phenomenon has long been known, but its practical application has not even been thought of, because it was known on the basis of theoretical considerations that when emitting visible light the luminous efficiency of braking radiation is very low. Thus for instance, W. Finkelburg, when discussing these pehenomena says, on page 91 of his work "Kontinuierliche Spektren" (published by J. Springer, 1938) substantially what follows:

"No use has been made up to now of optical braking radiation for the purpose of lighting technique, and its application in any substantial extent can, owing to its poor efficiency, hardly be expected in the future either."

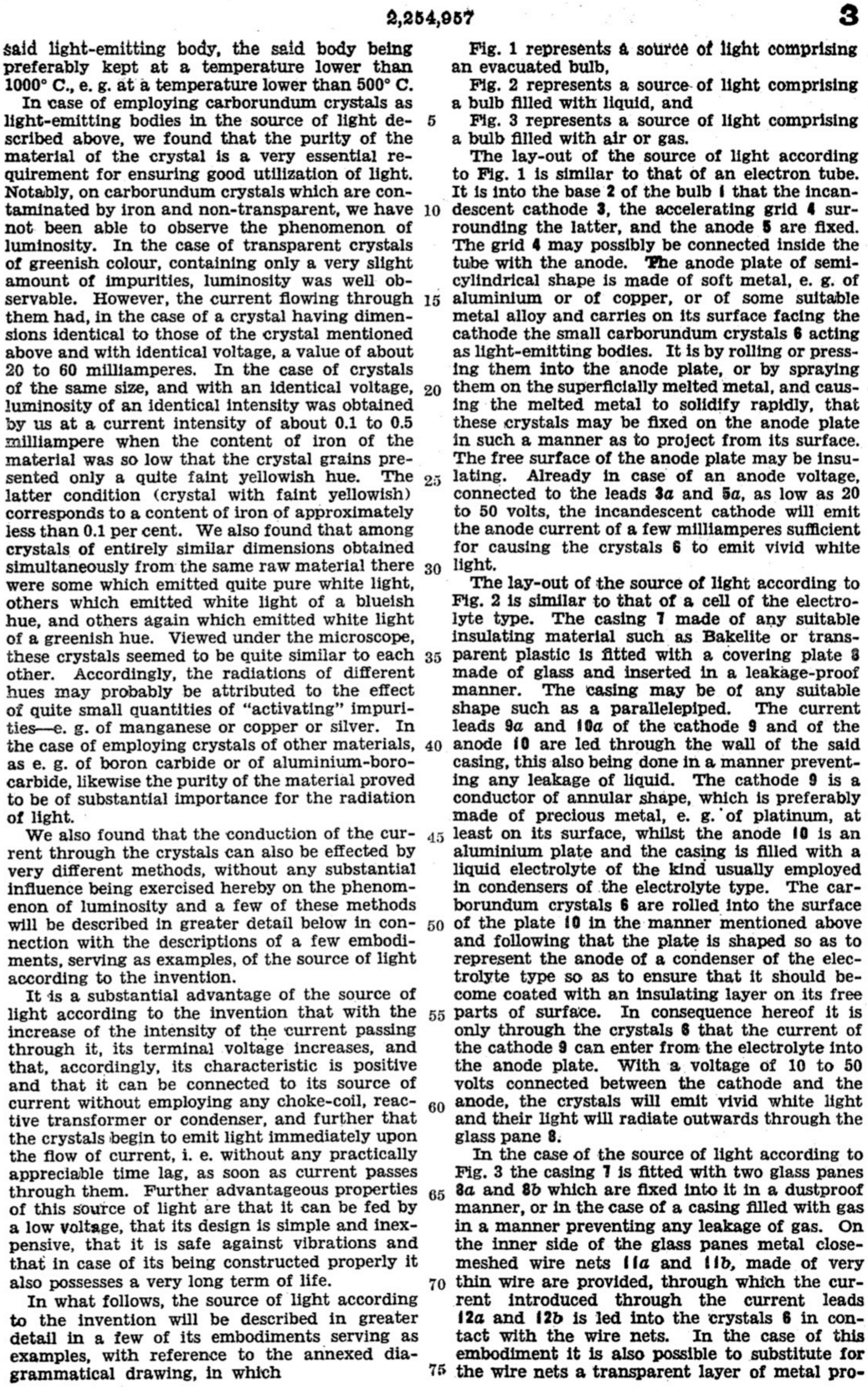
Finally, luminous phenomena were observed also in insulating liquids, if the latter were subjected to the action of a very intense electric field; thus, for instance, a mixture of diphenyl oxide and diphenyl placed between two electrodes situated at a distance of about one millimetre from each other has supplied light of sufficient intensity to enable a well-visible photographic picture to be taken of the phenomenon.

The source of light according to the invention is based on our discovery of the fact that the whole mass of certain transparent or at least semi-transparent electrically semi-conductive crystals becomes luminous when electric current passes through them, notwithstanding the fact that their temperature remains far below the temperature at which they would emit the thermal radiation corresponding to the light emitted by them. Thus, for instance, a transparent crystal of carborundum the dimensions of which are approximately between 0.1 and 1 millimetre and which is made from raw materials which are entirely pure, and particularly devoid of any contents of iron, will, when held fast between two electrodes, between which the voltage amounts in order of magnitude to 10 volts, in which case a current of about 0.1 milliampere passes through the crystal, become luminous so as to emit vivid white light, notably not only at the points of contact with the electrodes but in the whole mass of the crystal. This light can evidently not be considered to represent any thermal radiation, because it is only when employing a substantially higher current intensity and voltage that the crystal would begin to enter into red incandescence.

This new phenomenon can best be compared to fluorescence set up under the action of cathode rays, but with the substantial difference that it is not necessary to accelerate the electrons specially in a vacuum, the said electrons probably becoming accelerated in the crystal itself or in the closing layer existing on the surface of the crystal, and using their energy for generating the fluorescence of the crystal. The difference as compared to generation by means of cathode rays is, apart from the nature of the light-emitting substances, also substantial from the point of view that the voltage sufficient for generating the light is smaller by a whole order of magnitude than the one required in case of cathode rays. Notably, in the case of generation by means of cathode rays, a voltage of at least a few hundred, and possibly of several thousand volts is required, whereas the phenomenon constituting the basis of the invention presents itself already at voltages below 10 volts. Nor can the phenomenon be considered identical with the braking radiation described in what has preceded, because in braking radiation the radiation is developed by deceleration of electrons in a layer of less than 10^{-6} mm. thickness whereas in the present phenomenon the luminosity can be observed through the whole mass of the crystal. Accordingly what takes place probably is not that the energy of the electrons is being braked with concurrent emission of radiation, but that it causes the crystal to become fluorescent. Accordingly, if this assumption is correct, the difference between the radiation obtained in connection with the new phenomenon and that obtained in braking radiation is of a character similar to that of the difference between the fluorescent radiation generated by cathode rays produced with the aid of voltage of several thousand volts and the X-ray radiation generated by cathode rays of the same kind. Furthermore, the new phenomenon differs substantially also from the electro-luminescence set up in insulating liquids at high field intensities which has been described above, because this electro-luminescence is only set up at very high field intensities whereas a few volts are sufficient for producing the luminous phenomenon observed by us. This substantial difference is not only of quantitative but also of qualitative importance, seeing that the insulating substance contains no free electrons, and that it is therefore necessary to release them by the employment of high voltages, whereas in a conductor or semiconductor such electrons are available. We would, however, emphasize, that the correctness or incorrectness of the theoretical explanation attempted above of the new phenomenon discovered by us does not affect the substance of our invention, as it is a fact of experience that, in case the measures mentioned in the present specificatiion are strictly observed, it is possible to produce luminous radiation by means of the source of light according to the invention.

What is characteristic for the source of light according to the invention is therefore, according to what has been said above, that is light-emitting body is a transparent or semi-transparent, electrically conductive or semiconductive solid body radiating light under the direct effect of the current flowing through it. By direct effect we mean that, it is not in consequence of the thermal effect of the current flowing through it that the solid light-emitting body of the source of light according to the invention radiates light, the situation being thus contrary to the one existing with the incandescent bodies of the usual kinds of electric incandescent lamps, in which it is the thermal effect that represents the cause directly producing the radiation, and in which it is only indirectly, owing to the production of this thermal effect, that the electric current produces the luminous radiation, it being in fact immaterial for the light radiation of the incandescent body whether it is by means of electric current or by any other means that it is brought into a condition of incandescence. The solid light emitting body of the source of light according to the invention, on the other hand, is kept by the current flowing through it at a temperature lower than the one necessary for emitting the thermal radiation corresponding to the light radiated by the

Figure B.212: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.



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said light-emitting body, the said body being preferably kept at a temperature lower than 1000° C., e. g. at a temperature lower than 500° C.

In case of employing carborundum crystals as light-emitting bodies in the source of light described above, we found that the purity of the material of the crystal is a very essential requirement for ensuring good utilization of light. Notably, on carborundum crystals which are contaminated by iron and non-transparent, we have not been able to observe the phenomenon of luminosity. In the case of transparent crystals of greenish colour, containing only a very slight amount of impurities, luminosity was well observable. However, the current flowing through them had, in the case of a crystal having dimensions identical to those of the crystal mentioned above and with identical voltage, a value of about 20 to 60 milliamperes. In the case of crystals of the same size, and with an identical voltage, luminosity of an identical intensity was obtained by us at a current intensity of about 0.1 to 0.5 milliampere when the content of iron of the material was so low that the crystal grains presented only a quite faint yellowish hue. The latter condition (crystal with faint yellowish) corresponds to a content of iron of approximately less than 0.1 per cent. We also found that among crystals of entirely similar dimensions obtained simultaneously from the same raw material there were some which emitted quite pure white light, others which emitted white light of a blueish hue, and others again which emitted white light of a greenish hue. Viewed under the microscope, these crystals seemed to be quite similar to each other. Accordingly, the radiations of different hues may probably be attributed to the effect of quite small quantities of "activating" impurities—e. g. of manganese or copper or silver. In the case of employing crystals of other materials, as e. g. of boron carbide or of aluminium-borocarbide, likewise the purity of the material proved to be of substantial importance for the radiation of light.

We also found that the conduction of the current through the crystals can also be effected by very different methods, without any substantial influence being exercised hereby on the phenomenon of luminosity and a few of these methods will be described in greater detail below in connection with the descriptions of a few embodiments, serving as examples, of the source of light according to the invention.

It is a substantial advantage of the source of light according to the invention that with the increase of the intensity of the current passing through it, its terminal voltage increases, and that, accordingly, its characteristic is positive and that it can be connected to its source of current without employing any choke-coil, reactive transformer or condenser, and further that the crystals begin to emit light immediately upon the flow of current, i. e. without any practically appreciable time lag, as soon as current passes through them. Further advantageous properties of this source of light are that it can be fed by a low voltage, that its design is simple and inexpensive, that it is safe against vibrations and that in case of its being constructed properly it also possesses a very long term of life.

In what follows, the source of light according to the invention will be described in greater detail in a few of its embodiments serving as examples, with reference to the annexed diagrammatical drawing, in which

Fig. 1 represents a source of light comprising an evacuated bulb,

Fig. 2 represents a source of light comprising a bulb filled with liquid, and

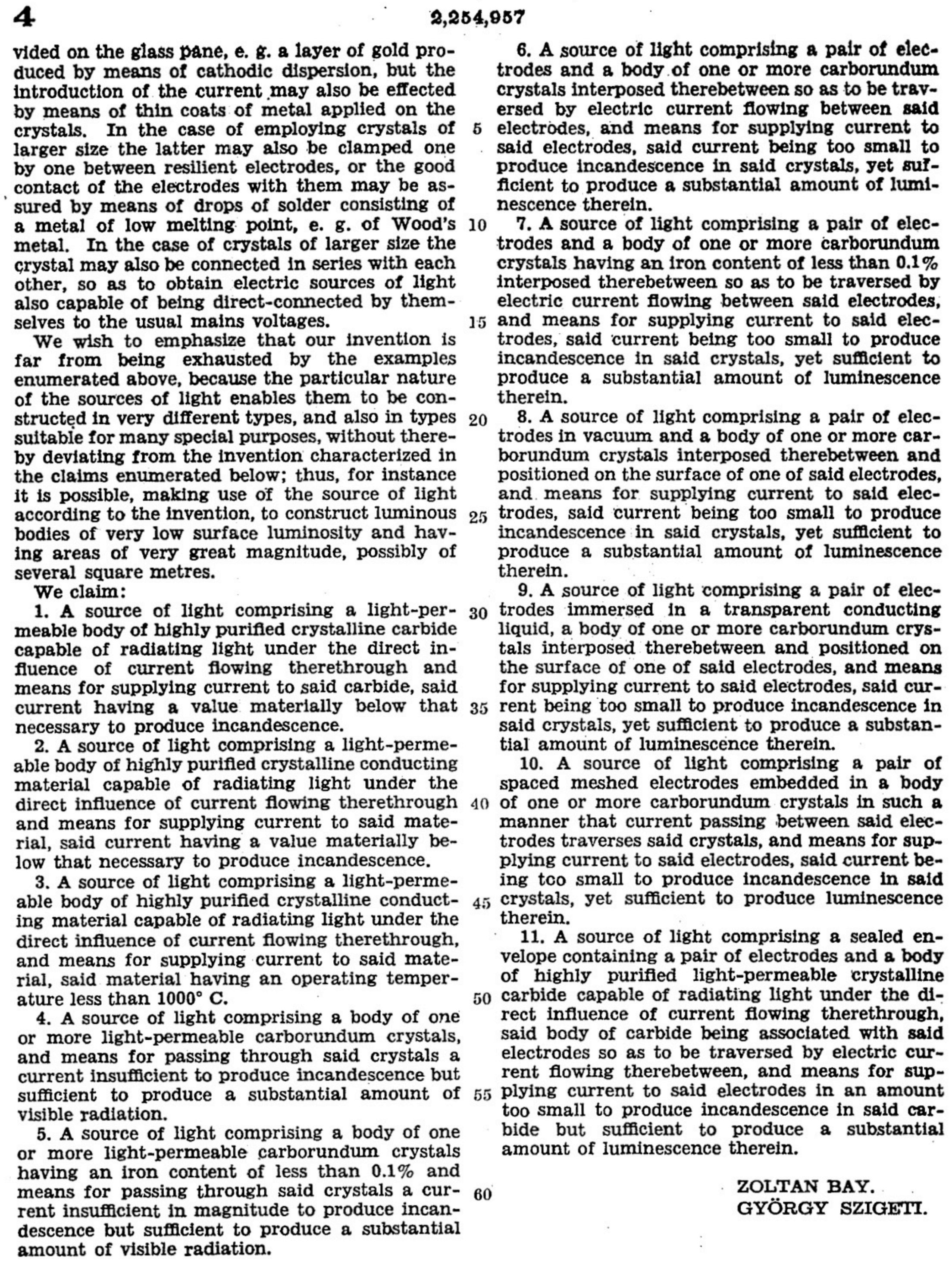
Fig. 3 represents a source of light comprising a bulb filled with air or gas.

The lay-out of the source of light according to Fig. 1 is similar to that of an electron tube. It is into the base 2 of the bulb 1 that the incandescent cathode 3, the accelerating grid 4 surrounding the latter, and the anode 5 are fixed. The grid 4 may possibly be connected inside the tube with the anode. The anode plate of semi-cylindrical shape is made of soft metal, e. g. of aluminium or of copper, or of some suitable metal alloy and carries on its surface facing the cathode the small carborundum crystals 6 acting as light-emitting bodies. It is by rolling or pressing them into the anode plate, or by spraying them on the superficially melted metal, and causing the melted metal to solidify rapidly, that these crystals may be fixed on the anode plate in such a manner as to project from its surface. The free surface of the anode plate may be insulating. Already in case of an anode voltage, connected to the leads 3*a* and 5*a*, as low as 20 to 50 volts, the incandescent cathode will emit the anode current of a few milliamperes sufficient for causing the crystals 6 to emit vivid white light.

The lay-out of the source of light according to Fig. 2 is similar to that of a cell of the electrolyte type. The casing 7 made of any suitable insulating material such as Bakelite or transparent plastic is fitted with a covering plate 8 made of glass and inserted in a leakage-proof manner. The casing may be of any suitable shape such as a parallelepiped. The current leads 9*a* and 10*a* of the cathode 9 and of the anode 10 are led through the wall of the said casing, this also being done in a manner preventing any leakage of liquid. The cathode 9 is a conductor of annular shape, which is preferably made of precious metal, e. g. of platinum, at least on its surface, whilst the anode 10 is an aluminium plate and the casing is filled with a liquid electrolyte of the kind usually employed in condensers of the electrolyte type. The carborundum crystals 6 are rolled into the surface of the plate 10 in the manner mentioned above and following that the plate is shaped so as to represent the anode of a condenser of the electrolyte type so as to ensure that it should become coated with an insulating layer on its free parts of surface. In consequence hereof it is only through the crystals 6 that the current of the cathode 9 can enter from the electrolyte into the anode plate. With a voltage of 10 to 50 volts connected between the cathode and the anode, the crystals will emit vivid white light and their light will radiate outwards through the glass pane 8.

In the case of the source of light according to Fig. 3 the casing 7 is fitted with two glass panes 8*a* and 8*b* which are fixed into it in a dustproof manner, or in the case of a casing filled with gas in a manner preventing any leakage of gas. On the inner side of the glass panes metal close-meshed wire nets 11*a* and 11*b*, made of very thin wire are provided, through which the current introduced through the current leads 12*a* and 12*b* is led into the crystals 6 in contact with the wire nets. In the case of this embodiment it is also possible to substitute for the wire nets a transparent layer of metal pro-

Figure B.213: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.



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vided on the glass pane, e. g. a layer of gold produced by means of cathodic dispersion, but the introduction of the current may also be effected by means of thin coats of metal applied on the crystals. In the case of employing crystals of larger size the latter may also be clamped one by one between resilient electrodes, or the good contact of the electrodes with them may be assured by means of drops of solder consisting of a metal of low melting point, e. g. of Wood's metal. In the case of crystals of larger size the crystal may also be connected in series with each other, so as to obtain electric sources of light also capable of being direct-connected by themselves to the usual mains voltages.

We wish to emphasize that our invention is far from being exhausted by the examples enumerated above, because the particular nature of the sources of light enables them to be constructed in very different types, and also in types suitable for many special purposes, without thereby deviating from the invention characterized in the claims enumerated below; thus, for instance it is possible, making use of the source of light according to the invention, to construct luminous bodies of very low surface luminosity and having areas of very great magnitude, possibly of several square metres.

We claim:

1. A source of light comprising a light-permeable body of highly purified crystalline carbide capable of radiating light under the direct influence of current flowing therethrough and means for supplying current to said carbide, said current having a value materially below that necessary to produce incandescence.

2. A source of light comprising a light-permeable body of highly purified crystalline conducting material capable of radiating light under the direct influence of current flowing therethrough and means for supplying current to said material, said current having a value materially below that necessary to produce incandescence.

3. A source of light comprising a light-permeable body of highly purified crystalline conducting material capable of radiating light under the direct influence of current flowing therethrough, and means for supplying current to said material, said material having an operating temperature less than 1000° C.

4. A source of light comprising a body of one or more light-permeable carborundum crystals, and means for passing through said crystals a current insufficient to produce incandescence but sufficient to produce a substantial amount of visible radiation.

5. A source of light comprising a body of one or more light-permeable carborundum crystals having an iron content of less than 0.1% and means for passing through said crystals a current insufficient in magnitude to produce incandescence but sufficient to produce a substantial amount of visible radiation.

6. A source of light comprising a pair of electrodes and a body of one or more carborundum crystals interposed therebetween so as to be traversed by electric current flowing between said electrodes, and means for supplying current to said electrodes, said current being too small to produce incandescence in said crystals, yet sufficient to produce a substantial amount of luminescence therein.

7. A source of light comprising a pair of electrodes and a body of one or more carborundum crystals having an iron content of less than 0.1% interposed therebetween so as to be traversed by electric current flowing between said electrodes, and means for supplying current to said electrodes, said current being too small to produce incandescence in said crystals, yet sufficient to produce a substantial amount of luminescence therein.

8. A source of light comprising a pair of electrodes in vacuum and a body of one or more carborundum crystals interposed therebetween and positioned on the surface of one of said electrodes, and means for supplying current to said electrodes, said current being too small to produce incandescence in said crystals, yet sufficient to produce a substantial amount of luminescence therein.

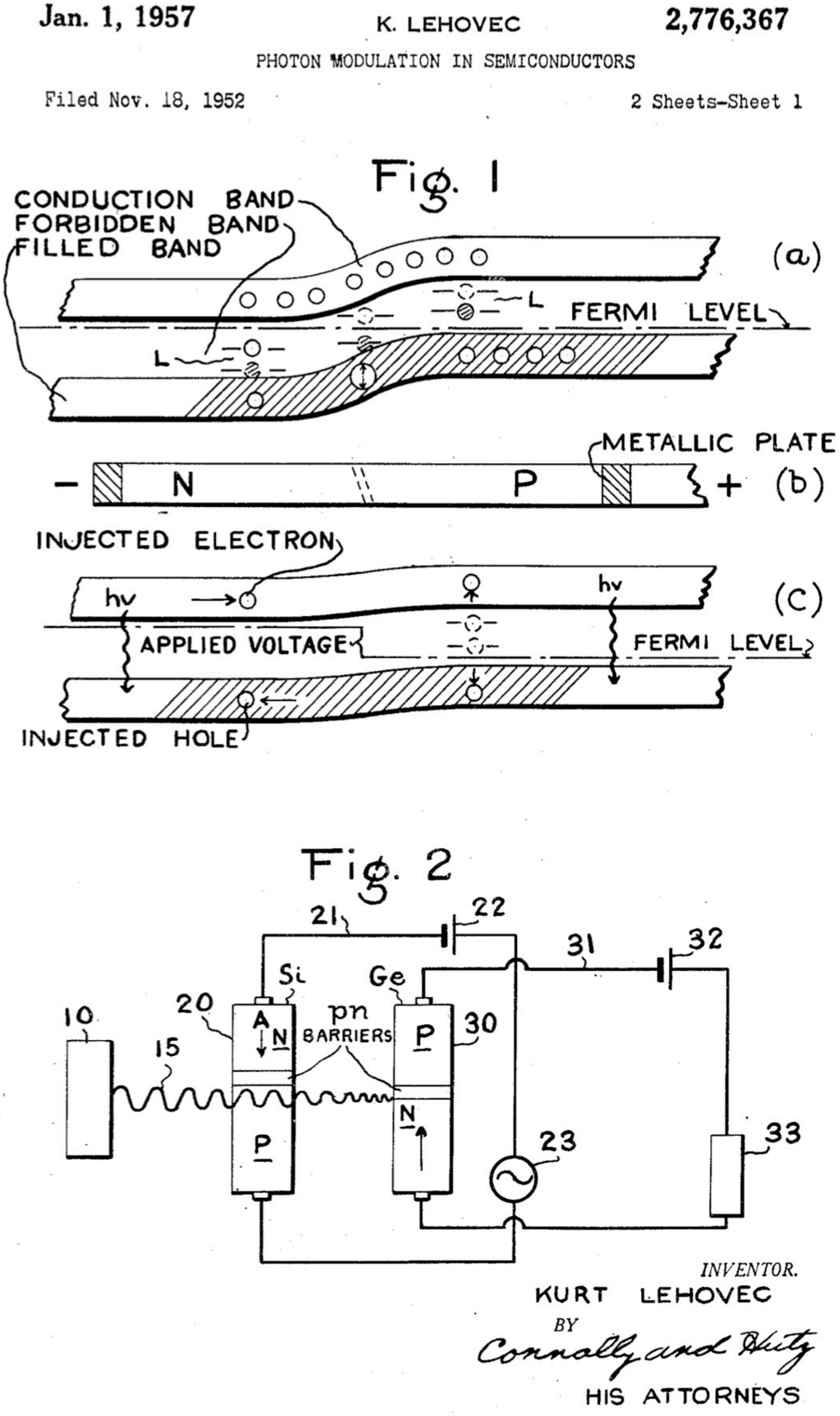
9. A source of light comprising a pair of electrodes immersed in a transparent conducting liquid, a body of one or more carborundum crystals interposed therebetween and positioned on the surface of one of said electrodes, and means for supplying current to said electrodes, said current being too small to produce incandescence in said crystals, yet sufficient to produce a substantial amount of luminescence therein.

10. A source of light comprising a pair of spaced meshed electrodes embedded in a body of one or more carborundum crystals in such a manner that current passing between said electrodes traverses said crystals, and means for supplying current to said electrodes, said current being too small to produce incandescence in said crystals, yet sufficient to produce luminescence therein.

11. A source of light comprising a sealed envelope containing a pair of electrodes and a body of highly purified light-permeable crystalline carbide capable of radiating light under the direct influence of current flowing therethrough, said body of carbide being associated with said electrodes so as to be traversed by electric current flowing therebetween, and means for supplying current to said electrodes in an amount too small to produce incandescence in said carbide but sufficient to produce a substantial amount of luminescence therein.

ZOLTAN BAY.
GYÖRGY SZIGETI.

Figure B.214: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.



Jan. 1, 1957 K. LEHOVEC **2,776,367**

PHOTON MODULATION IN SEMICONDUCTORS

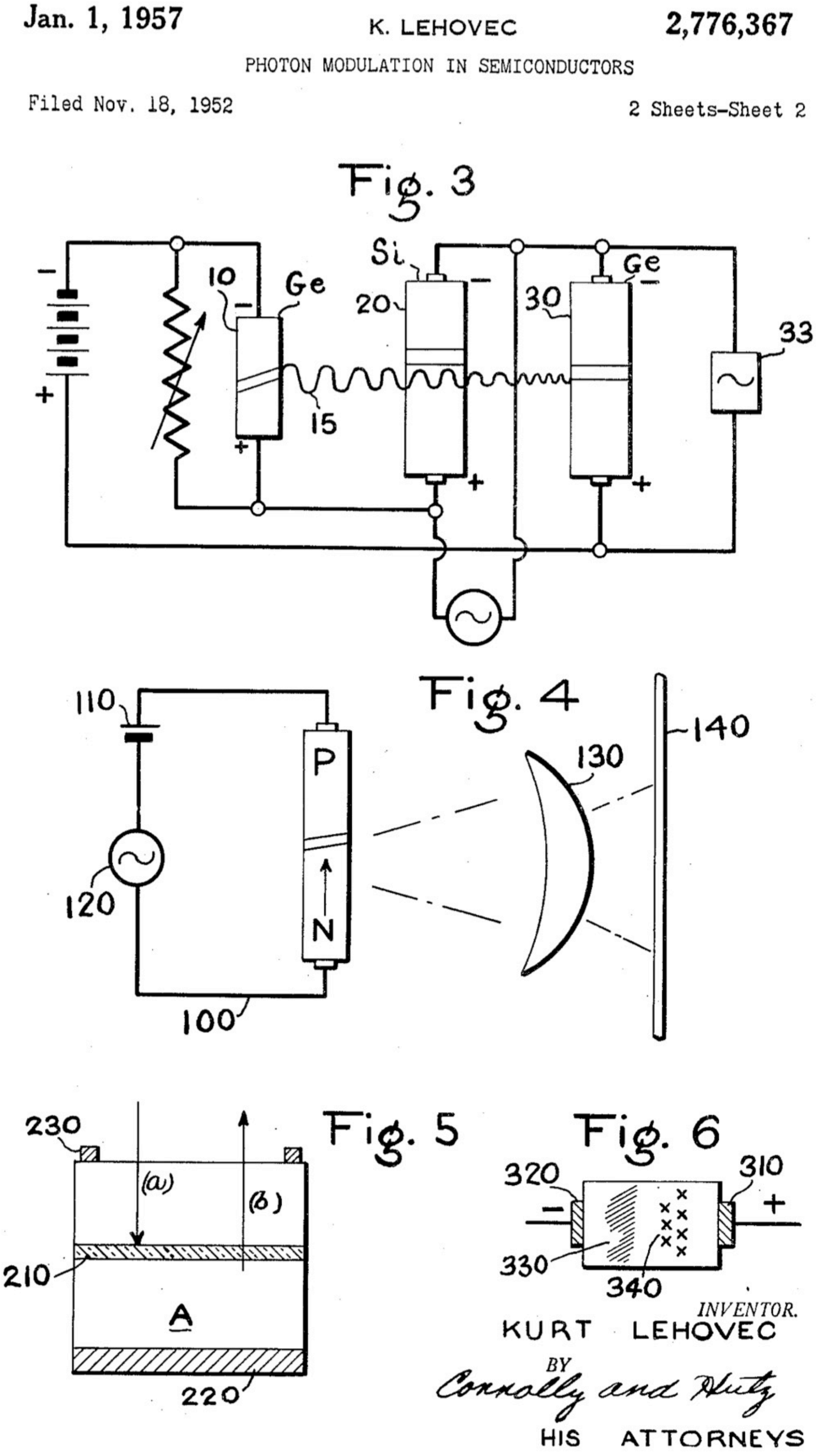
Filed Nov. 18, 1952 2 Sheets-Sheet 1

Fig. 1

Fig. 2

INVENTOR.
KURT LEHOVEC
BY
Connolly and Hutz
HIS ATTORNEYS

Figure B.215: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



Jan. 1, 1957 K. LEHOVEC **2,776,367**

PHOTON MODULATION IN SEMICONDUCTORS

Filed Nov. 18, 1952 2 Sheets-Sheet 2

INVENTOR.
KURT LEHOVEC
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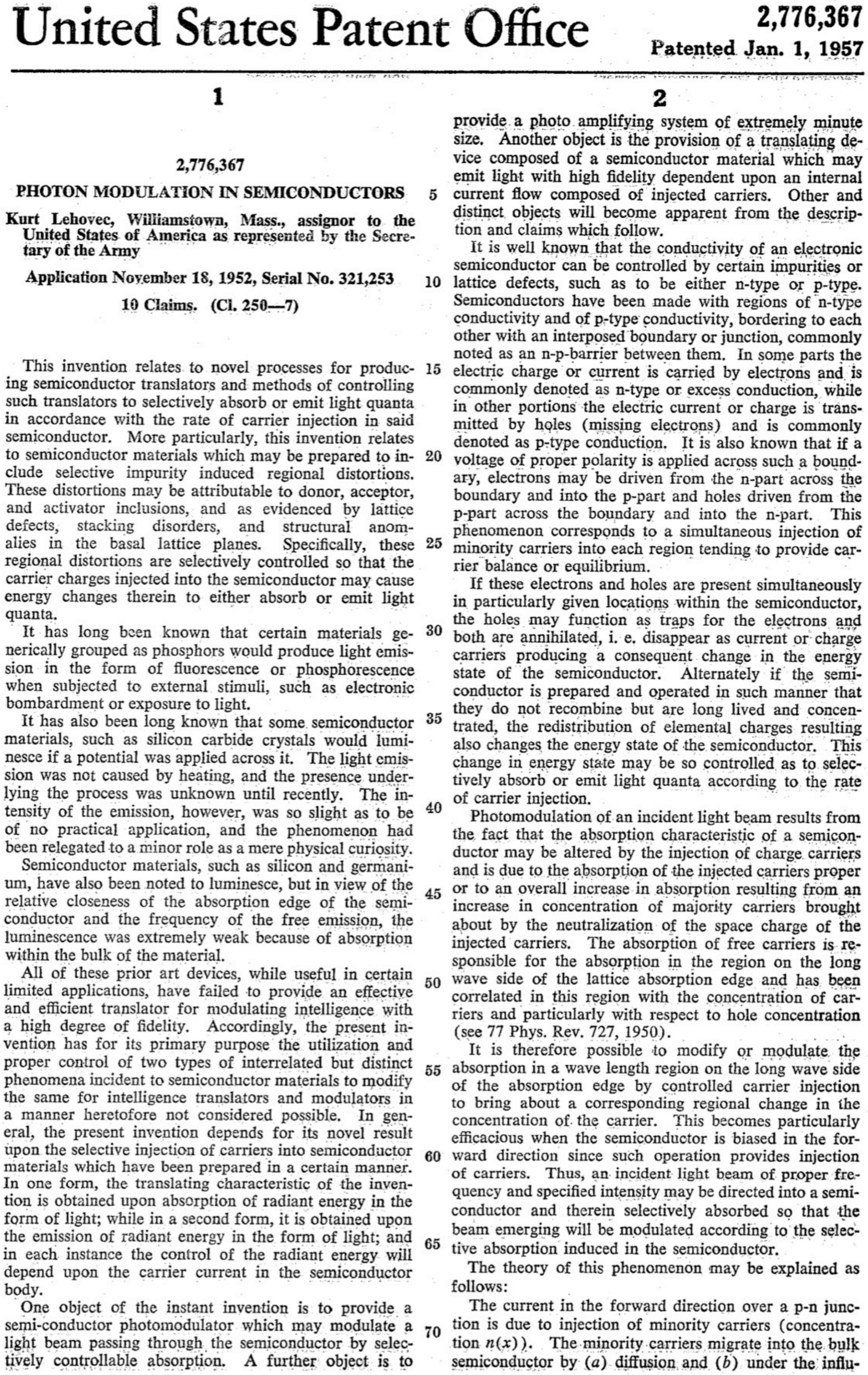
HIS ATTORNEYS

Figure B.216: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



United States Patent Office

2,776,367

Patented Jan. 1, 1957

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2,776,367

PHOTON MODULATION IN SEMICONDUCTORS

Kurt Lehovec, Williamstown, Mass., assignor to the United States of America as represented by the Secretary of the Army

Application November 18, 1952, Serial No. 321,253

10 Claims. (Cl. 250—7)

This invention relates to novel processes for producing semiconductor translators and methods of controlling such translators to selectively absorb or emit light quanta in accordance with the rate of carrier injection in said semiconductor. More particularly, this invention relates to semiconductor materials which may be prepared to include selective impurity induced regional distortions. These distortions may be attributable to donor, acceptor, and activator inclusions, and as evidenced by lattice defects, stacking disorders, and structural anomalies in the basal lattice planes. Specifically, these regional distortions are selectively controlled so that the carrier charges injected into the semiconductor may cause energy changes therein to either absorb or emit light quanta.

It has long been known that certain materials generically grouped as phosphors would produce light emission in the form of fluorescence or phosphorescence when subjected to external stimuli, such as electronic bombardment or exposure to light.

It has also been long known that some semiconductor materials, such as silicon carbide crystals would luminesce if a potential was applied across it. The light emission was not caused by heating, and the presence underlying the process was unknown until recently. The intensity of the emission, however, was so slight as to be of no practical application, and the phenomenon had been relegated to a minor role as a mere physical curiosity.

Semiconductor materials, such as silicon and germanium, have also been noted to luminesce, but in view of the relative closeness of the absorption edge of the semiconductor and the frequency of the free emission, the luminescence was extremely weak because of absorption within the bulk of the material.

All of these prior art devices, while useful in certain limited applications, have failed to provide an effective and efficient translator for modulating intelligence with a high degree of fidelity. Accordingly, the present invention has for its primary purpose the utilization and proper control of two types of interrelated but distinct phenomena incident to semiconductor materials to modify the same for intelligence translators and modulators in a manner heretofore not considered possible. In general, the present invention depends for its novel result upon the selective injection of carriers into semiconductor materials which have been prepared in a certain manner. In one form, the translating characteristic of the invention is obtained upon absorption of radiant energy in the form of light; while in a second form, it is obtained upon the emission of radiant energy in the form of light; and in each instance the control of the radiant energy will depend upon the carrier current in the semiconductor body.

One object of the instant invention is to provide a semi-conductor photomodulator which may modulate a light beam passing through the semiconductor by selectively controllable absorption. A further object is to

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provide a photo amplifying system of extremely minute size. Another object is the provision of a translating device composed of a semiconductor material which may emit light with high fidelity dependent upon an internal current flow composed of injected carriers. Other and distinct objects will become apparent from the description and claims which follow.

It is well known that the conductivity of an electronic semiconductor can be controlled by certain impurities or lattice defects, such as to be either n-type or p-type. Semiconductors have been made with regions of n-type conductivity and of p-type conductivity, bordering to each other with an interposed boundary or junction, commonly noted as an n-p-barrier between them. In some parts the electric charge or current is carried by electrons and is commonly denoted as n-type or excess conduction, while in other portions the electric current or charge is transmitted by holes (missing electrons) and is commonly denoted as p-type conduction. It is also known that if a voltage of proper polarity is applied across such a boundary, electrons may be driven from the n-part across the boundary and into the p-part and holes driven from the p-part across the boundary and into the n-part. This phenomenon corresponds to a simultaneous injection of minority carriers into each region tending to provide carrier balance or equilibrium.

If these electrons and holes are present simultaneously in particularly given locations within the semiconductor, the holes may function as traps for the electrons and both are annihilated, i. e. disappear as current or charge carriers producing a consequent change in the energy state of the semiconductor. Alternately if the semiconductor is prepared and operated in such manner that they do not recombine but are long lived and concentrated, the redistribution of elemental charges resulting also changes the energy state of the semiconductor. This change in energy state may be so controlled as to selectively absorb or emit light quanta according to the rate of carrier injection.

Photomodulation of an incident light beam results from the fact that the absorption characteristic of a semiconductor may be altered by the injection of charge carriers and is due to the absorption of the injected carriers proper or to an overall increase in absorption resulting from an increase in concentration of majority carriers brought about by the neutralization of the space charge of the injected carriers. The absorption of free carriers is responsible for the absorption in the region on the long wave side of the lattice absorption edge and has been correlated in this region with the concentration of carriers and particularly with respect to hole concentration (see 77 Phys. Rev. 727, 1950).

It is therefore possible to modify or modulate the absorption in a wave length region on the long wave side of the absorption edge by controlled carrier injection to bring about a corresponding regional change in the concentration of the carrier. This becomes particularly efficacious when the semiconductor is biased in the forward direction since such operation provides injection of carriers. Thus, an incident light beam of proper frequency and specified intensity may be directed into a semiconductor and therein selectively absorbed so that the beam emerging will be modulated according to the selective absorption induced in the semiconductor.

The theory of this phenomenon may be explained as follows:

The current in the forward direction over a p-n junction is due to injection of minority carriers (concentration $n(x)$). The minority carriers migrate into the bulk semiconductor by (a) diffusion and (b) under the influ-

Figure B.217: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).

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ence of an electric field. The migration is terminated by recombination with majority carriers.

For a quantitative estimate of $n(x)$ we shall assume that diffusion current exceeds largely the field current of injected carriers. The condition of continuity takes then the simple form

$$\frac{d^2n}{D_{dx}2}=-\frac{n}{t} \qquad (1)$$

($D=ykA/e$ diffusion constant of injected carriers, y=mobility, k=Boltzman constant, A=absolute temperature, e=elementary charge, t=life time of injected carriers.)

Integration gives

$$n=n_0\exp\left(-\frac{x}{\sqrt{Dt}}\right) \qquad (2)$$

where n_0 is the concentration of minority carriers immediately adjacent to the junction. The concentration n_0 can be expressed by the current I, using the equation

$$I=HWDe\frac{dn}{dx}\bigg|_{x=0}=HWn_0e\sqrt{\frac{D}{t}} \qquad (3)$$

(H=height of the rectangular junction and W=width). Hence,

$$n_0=\frac{I}{HWe}\sqrt{\frac{t}{D}} \qquad (4)$$

According to (2), n_0 decays by a factor $1/e=1/2.72$ at the distance

$$L=\sqrt{Dt} \qquad (5)$$

With $t\approx 100$ μsec. and $D\approx 50$ cm.^{2}/sec., which appear to be values of reasonable order of magnitude for germanium and silicon of proper preparation, we obtain $L\approx 0.07$ cm.

Assume a light beam of intensity per unit area J (expressed in quanta per cm.^{2} per second) and of rectangular across section (height H, width X) incident on the semiconductor parallel to the junction and to the side of width W. The fraction (R) of the light beam is reflected and the intensity

$$Q=JXH(1-R)\ \exp\ (-WT) \qquad (6)$$

emerges from the semiconductor; T can be modulated by the carrier injection.

The change of light intensity with current is linear for sufficiently small values of current. Then we may set

$$T\approx T_0+\Delta T \qquad (7)$$

and

$$Q=Q_0+\Delta Q \qquad (8)$$

and we obtain

$$\Delta Q\approx JXH(1-R)\ \exp\ (-WT_0)W\Delta T \qquad (9)$$

Maximum value $(\Delta Q)m$ is obtained by choosing the width of the bar

$$W=\frac{1}{T_0} \qquad (10)$$

$$(\Delta Q)m=\frac{JXH(1-R)}{2.72}\,\frac{\Delta T}{T_0} \qquad (11)$$

Since ΔT is proportional to $\Delta n_0{}^2$, we have

$$\Delta T=\Delta n_0/p \qquad (12)$$

where p is a constant $\sim 10^{16}$cm.$^{-2}$ for silicon. Replace n_0 in (12) by using (4) and insert the value of ΔT so obtained into (11) to obtain

$$(\Delta Q)m=\frac{JX(1-R)-I/e}{2.72\cdot p}\,\frac{\bar{t}}{D} \qquad (13)$$

Since only light passing within a distance $\sim$L from the junction will be modulated, one shall choose $X\approx L$.

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Then from (13) and (5), the efficiency of light modulation may be calculated

$$\frac{(\Delta Q)m}{\Delta I/e}=\frac{J(1-R)t}{2.72\cdot p} \qquad (14)$$

The numerical factor $(1-R)/2.72$ is of the order of 0.3. For $t\approx 10^{-4}$ sec., and $p\sim 10^{16}$cm.$^{-2}$, efficiencies larger than unity may be obtained for light intensities larger than 3 x 10^{20} quanta/cm.^{2}sec. (for light of near infrared about 20 watts/cm.^{2}).

After having discussed in some detail the change in absorption of a light beam incident into a semiconductor containing a p-n-barrier, I shall turn to the creation of light by the injection of carriers over a p-n-barrier. It has already been noted that in a region where electrons and holes are present simultaneously, annihilation of the electrons and holes takes place. In the annihilation process energy is disposed of either as heat or as radiation. The following part of the instant invention concerns means for accentuating the recombination of electrons and holes with light emission as well as the creation of conditions leading to the simultaneous presence of electrons and holes in the same region.

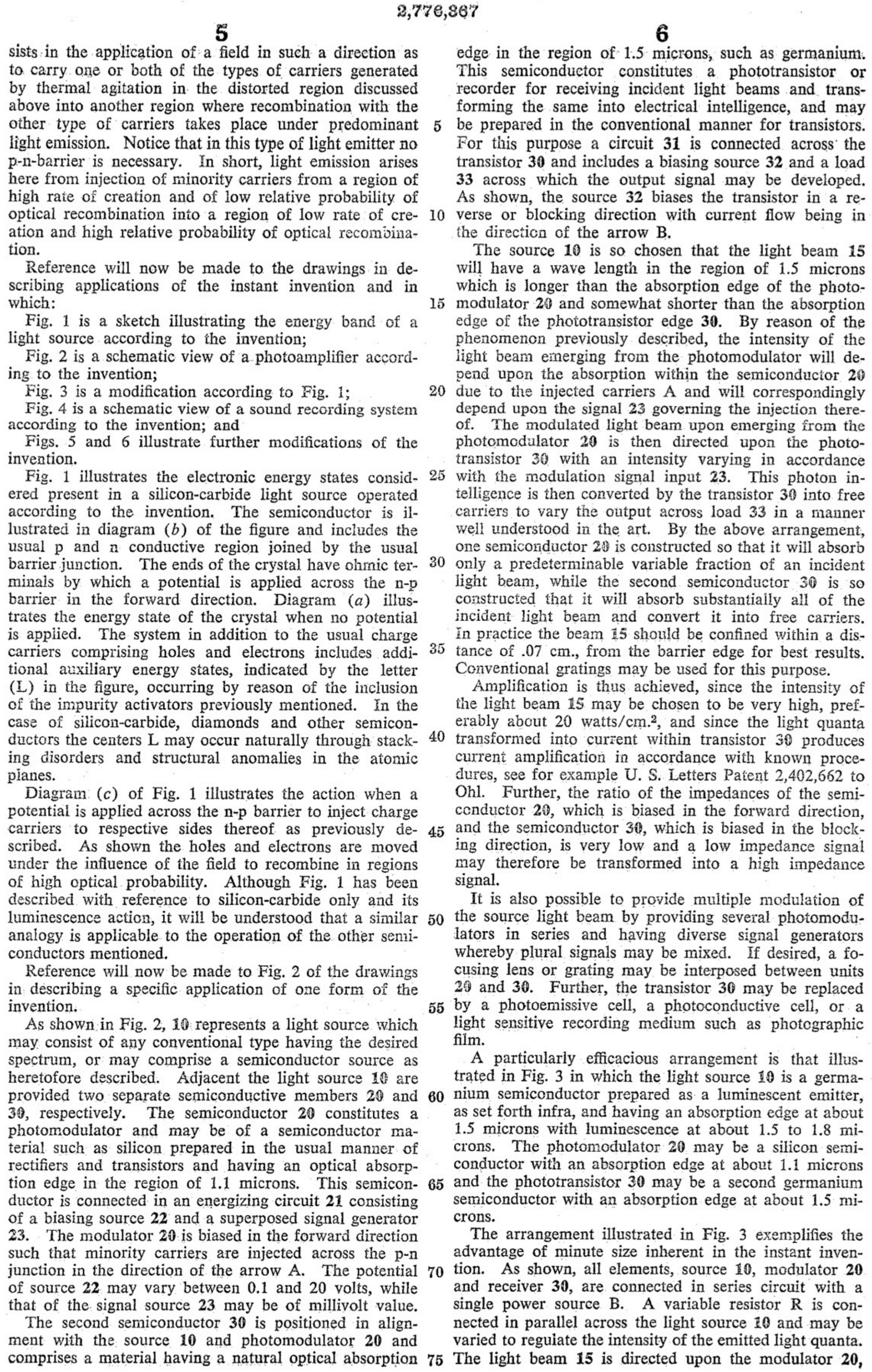
The accentuation of the recombination of electrons and holes under emission of light is done by inclusion of so-called activator-type impurities into the semiconductor close to the p-n-barrier. The activator types of impurities are selected from a group including manganese, silver, thallium, bismuth, copper, lead, europium, cerium, tin, samarium and zinc. These impurities induce emission centers in a manner analogous to that known for impurity activated phosphors.

This emission appears to be dependent upon the rate of recombination between holes and electrons corresponding to pair annihilation and therefore is directly proportional to pair production, i. e., the greater the number of electron-hole pairs produced in a divided and ununited state, the greater the pair annihilation subsequently resulting due to their recombination. Thus if a larger current is passed across the barrier junction more carriers of each type will be projected or injected over the barrier into the respective p and n areas, to increase the rate of reaction or pair annihilation and directly increase the emission intensity. Thus the light emission arises from the recombination of injected carriers, whereas the photomodulation discussed in the previous part of this disclosure arises from the absorption due to injected carriers. Light emission occurs at the termination of the life of injected carriers, whereas photomodulation occurs during the life of the injected carriers.

In practice, light emission or absorption due to the carrier injection may be obtained in various semiconductor materials including silicon-carbide, germanium, silicon and diamonds containing natural or accentuated p-n junctions in which the adjacent areas differ in the type of conductivity. The instant invention, however, is not limited to single crystals and may comprise materials which form solid solutions, for example, germanium and silicon or selenium and tellurium. In the case of the existence of mixed crystals in any composition, a transition from material A to material B within the single crystal may be achieved. These latter type p-n junctions may be conveniently referred to as "graded seal" junctions.

Another means of creating a high concentration of both holes and electrons in the same region is the following: a region of the semiconductor is distorted strongly by a large amount of impurities or by lattice defects such that the rate of recombination of electrons and holes (but not necessarily leading to light emission) is very high. It follows from well-known general considerations, that in such a region also the rate of creating of holes and electrons by thermal agitation is very high. The novel idea of this part of the instant invention con-

Figure B.218: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



sists in the application of a field in such a direction as to carry one or both of the types of carriers generated by thermal agitation in the distorted region discussed above into another region where recombination with the other type of carriers takes place under predominant light emission. Notice that in this type of light emitter no p-n-barrier is necessary. In short, light emission arises here from injection of minority carriers from a region of high rate of creation and of low relative probability of optical recombination into a region of low rate of creation and high relative probability of optical recombination.

Reference will now be made to the drawings in describing applications of the instant invention and in which:

Fig. 1 is a sketch illustrating the energy band of a light source according to the invention;

Fig. 2 is a schematic view of a photoamplifier according to the invention;

Fig. 3 is a modification according to Fig. 1;

Fig. 4 is a schematic view of a sound recording system according to the invention; and

Figs. 5 and 6 illustrate further modifications of the invention.

Fig. 1 illustrates the electronic energy states considered present in a silicon-carbide light source operated according to the invention. The semiconductor is illustrated in diagram (*b*) of the figure and includes the usual p and n conductive region joined by the usual barrier junction. The ends of the crystal have ohmic terminals by which a potential is applied across the n-p barrier in the forward direction. Diagram (*a*) illustrates the energy state of the crystal when no potential is applied. The system in addition to the usual charge carriers comprising holes and electrons includes additional auxiliary energy states, indicated by the letter (L) in the figure, occurring by reason of the inclusion of the impurity activators previously mentioned. In the case of silicon-carbide, diamonds and other semiconductors the centers L may occur naturally through stacking disorders and structural anomalies in the atomic planes.

Diagram (*c*) of Fig. 1 illustrates the action when a potential is applied across the n-p barrier to inject charge carriers to respective sides thereof as previously described. As shown the holes and electrons are moved under the influence of the field to recombine in regions of high optical probability. Although Fig. 1 has been described with reference to silicon-carbide only and its luminescence action, it will be understood that a similar analogy is applicable to the operation of the other semiconductors mentioned.

Reference will now be made to Fig. 2 of the drawings in describing a specific application of one form of the invention.

As shown in Fig. 2, **10** represents a light source which may consist of any conventional type having the desired spectrum, or may comprise a semiconductor source as heretofore described. Adjacent the light source **10** are provided two separate semiconductive members **20** and **30**, respectively. The semiconductor **20** constitutes a photomodulator and may be of a semiconductor material such as silicon prepared in the usual manner of rectifiers and transistors and having an optical absorption edge in the region of 1.1 microns. This semiconductor is connected in an energizing circuit **21** consisting of a biasing source **22** and a superposed signal generator **23**. The modulator **20** is biased in the forward direction such that minority carriers are injected across the p-n junction in the direction of the arrow A. The potential of source **22** may vary between 0.1 and 20 volts, while that of the signal source **23** may be of millivolt value.

The second semiconductor **30** is positioned in alignment with the source **10** and photomodulator **20** and comprises a material having a natural optical absorption edge in the region of 1.5 microns, such as germanium. This semiconductor constitutes a phototransistor or recorder for receiving incident light beams and transforming the same into electrical intelligence, and may be prepared in the conventional manner for transistors. For this purpose a circuit **31** is connected across the transistor **30** and includes a biasing source **32** and a load **33** across which the output signal may be developed. As shown, the source **32** biases the transistor in a reverse or blocking direction with current flow being in the direction of the arrow B.

The source **10** is so chosen that the light beam **15** will have a wave length in the region of 1.5 microns which is longer than the absorption edge of the photomodulator **20** and somewhat shorter than the absorption edge of the phototransistor edge **30**. By reason of the phenomenon previously described, the intensity of the light beam emerging from the photomodulator will depend upon the absorption within the semiconductor **20** due to the injected carriers A and will correspondingly depend upon the signal **23** governing the injection thereof. The modulated light beam upon emerging from the photomodulator **20** is then directed upon the phototransistor **30** with an intensity varying in accordance with the modulation signal input **23**. This photon intelligence is then converted by the transistor **30** into free carriers to vary the output across load **33** in a manner well understood in the art. By the above arrangement, one semiconductor **20** is constructed so that it will absorb only a predeterminable variable fraction of an incident light beam, while the second semiconductor **30** is so constructed that it will absorb substantially all of the incident light beam and convert it into free carriers. In practice the beam **15** should be confined within a distance of .07 cm., from the barrier edge for best results. Conventional gratings may be used for this purpose.

Amplification is thus achieved, since the intensity of the light beam **15** may be chosen to be very high, preferably about 20 watts/cm.^{2}, and since the light quanta transformed into current within transistor **30** produces current amplification in accordance with known procedures, see for example U. S. Letters Patent 2,402,662 to Ohl. Further, the ratio of the impedances of the semiconductor **20**, which is biased in the forward direction, and the semiconductor **30**, which is biased in the blocking direction, is very low and a low impedance signal may therefore be transformed into a high impedance signal.

It is also possible to provide multiple modulation of the source light beam by providing several photomodulators in series and having diverse signal generators whereby plural signals may be mixed. If desired, a focusing lens or grating may be interposed between units **20** and **30**. Further, the transistor **30** may be replaced by a photoemissive cell, a photoconductive cell, or a light sensitive recording medium such as photographic film.

A particularly efficacious arrangement is that illustrated in Fig. 3 in which the light source **10** is a germanium semiconductor prepared as a luminescent emitter, as set forth infra, and having an absorption edge at about 1.5 microns with luminescence at about 1.5 to 1.8 microns. The photomodulator **20** may be a silicon semiconductor with an absorption edge at about 1.1 microns and the phototransistor **30** may be a second germanium semiconductor with an absorption edge at about 1.5 microns.

The arrangement illustrated in Fig. 3 exemplifies the advantage of minute size inherent in the instant invention. As shown, all elements, source **10**, modulator **20** and receiver **30**, are connected in series circuit with a single power source B. A variable resistor R is connected in parallel across the light source **10** and may be varied to regulate the intensity of the emitted light quanta. The light beam **15** is directed upon the modulator **20**,

Figure B.219: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).

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modulated and subsequently passed to the transistor **30** as previously described. The modulation signal may be connected directly across **20** as shown. The modulated signal converted into charge carriers in unit **30** may be detected across an output load **33**. The formation of the semiconductor materials such as silicon or germanium for the photomodulator and phototransistor may be accomplished in the conventional manner and may include the use of donor and/or acceptor impurity traces; e. g. antimony, arsenic, phosphorus and nitrogen may be used for producing n-type conductivity in silicon and germanium; while gallium, indium, aluminum and boron may be used for producing p-type conductivity in germanium and silicon.

Reference will now be made to the form of the invention in which the production and annihilation of charge carriers results in the emission of light from a semiconductor.

Silicon-carbide crystals may be prepared to be luminescent by means of the usual pile growth system conventionally employed in commercial production of silicon-carbide, wherein mixtures of quartz and carbon are heated to unite and form silicon-carbide. To prepare luminescent crystals, the original pile mixture growth may be changed so that a n-type impurity, such as arsenic, may be included in the crystal, as by having traces of an arsenic compound placed in the original mixture. In addition, the activator impurities may be introduced into the pile at the same time. Thereafter the crystal is permitted to grow in the usual manner and at a predetermined stage may be removed and placed in a vacuum chamber and locally melted as by means of electron bombardment. Traces of a p-type impurity such as boron may be introduced into the melted areas and the crystal allowed to cool.

The activator impurities which have been found suitable for controlling luminescence may consist of one or more minute impurities, having a percentage ratio with respect to the semiconductor of between 0.001 and 5.0 percent, selected from the group consisting of silver, lead, manganese, bismuth, thallium, tin, copper, zinc, alloys of the preceding metals, and the rare earth metals notably cerium, europium and samarium.

The type of final product is bluish, greenish or pale yellow in color depending on the impurity and activator present and their concentrations. A surface oxide film may be removed by conventional means.

Subsequently low ohmic contacts are made at opposite ends of the crystal, one to the area which has not been melted and a second to the melted portion. These contacts may be made for example, by first binding zirconium to the crystal and then soldering or plating to the zirconium. Other methods of preparing low ohmic connections are described in U. S. Letters Patent 2,569,347, 2,502,488 and 2,402,663.

A silicon carbide semiconductor prepared by the above described procedure, and having manganese as an activator, may be connected in a control circuit **100** as illustrated in Fig. 4. A biasing source **110** is provided in the circuit and connected to bias the crystal in a forward direction at a potential of 20 volts. A signal source **120** is also included in the control circuit **100** to superimpose a varying signal. A lens **130** is positioned in front of the crystal in such manner as to focus the emitted radiant energy upon a moving photographic film **140**.

With this arrangement a wide band luminescent spectral emission, having a peak at approximately .55 micron and an intensity varying up to 1 watt/cm.^{2} was observed to emanate from the silicon carbide. The emission was projected through the lens **130** onto the film **140** to selectively expose portions of the moving film in accordance with variations in the luminescent intensity provided by signal variations in source **120**. This variation is substantially linear with the signal.

It was noted that the spectral distribution of the luminescent emission changed only slightly with current density and that upon reversal of the biasing, no emission occurred. Further, the spectral distribution was practically independent of applied field strength. It will thus be appreciated that the characteristics of the instant luminescent semiconductor substantially deviates from those known for the prior art type phosphors in which the luminescent spectrum was dependent upon frequency, field strength and current density.

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A further advantage of the instant light source is the fact that even with weak potentials across the barrier junction, separate luminescent piplike emissions are easily recognizable at high frequencies even in excess of 200,000 cyles/sec. The device is thus eminently suitable for sound reproduction and recording applications as above noted.

The silicon-carbide source may be operated with no bias and in fact luminesceses with a potential difference of only three volts in the forward direction. It is also possible to operate the device with a potential at or below such minimum in order that very weak signal currents may be particularly effective to produce easily detectable changes in the relative intensities of the emission.

The device is unusual in that it is substantially opaque to heat and has an extremely simple construction, high stability and long life.

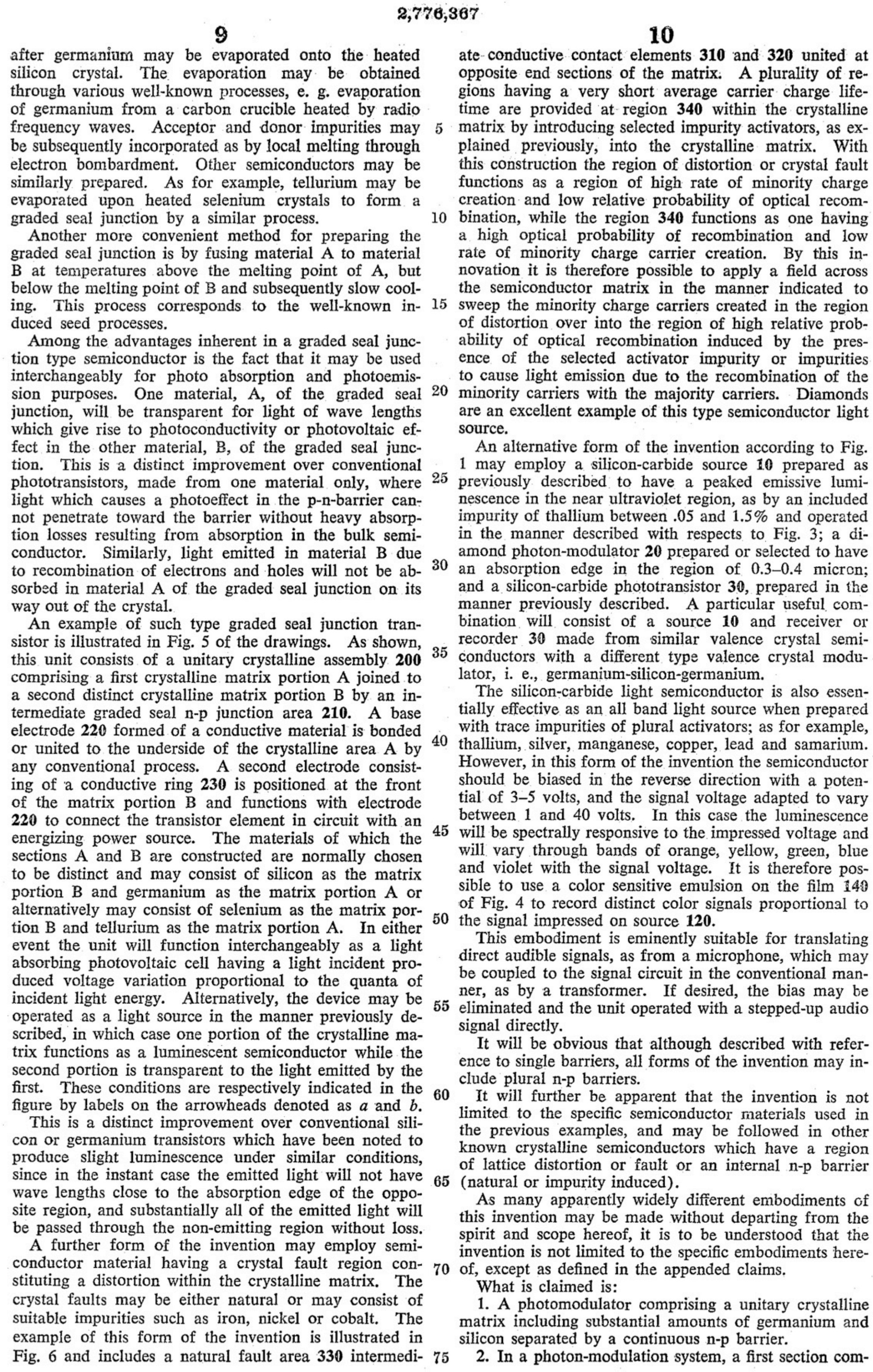
Suitable silicon-carbide light sources may also be prepared by a vapor condensation process in which silicon tetrafluoride and hydrogen are introduced into a vacuum chamber over a heated carbon filament in the presence of a hydrogen carbon arc mounted in close proximity to the film. Variations in the content of the silicon tetrafluoride and the temperature of the carbon filament produce predeterminable semiconductor structures. In some instances it may be advisable to combine toluene with silicon terafluoride in ratios between 2 to 1 and 10 to 1 to produce clear yellow crystals having a major portion thereof of n-type conductivity. Selected acceptor and donor impurities may then be introduced by local melting as previously described. Activators may also be incorporated in this manner, or alternatively, may be applied to the carbon filament prior to contacting it with the vapors.

In the case of germanium or silicon the preparation of the crystal growth may be in accordance with the prior art procedures disclosed by the patents to Scaff, No. 2,402,582, Ohl, No. 2,402,663 and Shockley, No. 2,569,347, with the added inclusion therein of significant activator impurities as previously noted. With the latter light sources, however, the applied potential across the barrier may be even less to produce an equivalent intensity, but the light emission occurs at infrared wave lengths.

A new type of luminescent semiconductor may also be prepared with a graded seal junction as indicated previously. It is well known that the spectral region of the strongest barrier photoeffect coincides with the long wave length absorption edge of the semiconductor material. If the wave length of the absorption edge on one side of the barrier differs from the wave length on the other side, one region will be transparent in a spectral distribution where the other region may have its maximum photosensitivity. Thus, if a transistor semiconductor is constructed of an n-type conductivity with one material and p-type conductivity with a second material, it may produce a large area junction which may be termed a "graded seal" having a medial absorption edge characteristic differing from those of the basic materials. Thus, light emissions in a region of one side of the barrier will lie outside of the absorption edge on the other side of the junction.

A suitable method for preparing the graded seal junction comprises the deposition of one material from the vapor phase, onto a heated substrate of the second material. For example, silicon crystals may be heated to a point below evaporation in a vacuum chamber. There-

Figure B.220: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



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after germanium may be evaporated onto the heated silicon crystal. The evaporation may be obtained through various well-known processes, e. g. evaporation of germanium from a carbon crucible heated by radio frequency waves. Acceptor and donor impurities may be subsequently incorporated as by local melting through electron bombardment. Other semiconductors may be similarly prepared. As for example, tellurium may be evaporated upon heated selenium crystals to form a graded seal junction by a similar process.

Another more convenient method for preparing the graded seal junction is by fusing material A to material B at temperatures above the melting point of A, but below the melting point of B and subsequently slow cooling. This process corresponds to the well-known induced seed processes.

Among the advantages inherent in a graded seal junction type semiconductor is the fact that it may be used interchangeably for photo absorption and photoemission purposes. One material, A, of the graded seal junction, will be transparent for light of wave lengths which give rise to photoconductivity or photovoltaic effect in the other material, B, of the graded seal junction. This is a distinct improvement over conventional phototransistors, made from one material only, where light which causes a photoeffect in the p-n-barrier cannot penetrate toward the barrier without heavy absorption losses resulting from absorption in the bulk semiconductor. Similarly, light emitted in material B due to recombination of electrons and holes will not be absorbed in material A of the graded seal junction on its way out of the crystal.

An example of such type graded seal junction transistor is illustrated in Fig. 5 of the drawings. As shown, this unit consists of a unitary crystalline assembly **200** comprising a first crystalline matrix portion A joined to a second distinct crystalline matrix portion B by an intermediate graded seal n-p junction area **210**. A base electrode **220** formed of a conductive material is bonded or united to the underside of the crystalline area A by any conventional process. A second electrode consisting of a conductive ring **230** is positioned at the front of the matrix portion B and functions with electrode **220** to connect the transistor element in circuit with an energizing power source. The materials of which the sections A and B are constructed are normally chosen to be distinct and may consist of silicon as the matrix portion B and germanium as the matrix portion A or alternatively may consist of selenium as the matrix portion B and tellurium as the matrix portion A. In either event the unit will function interchangeably as a light absorbing photovoltaic cell having a light incident produced voltage variation proportional to the quanta of incident light energy. Alternatively, the device may be operated as a light source in the manner previously described, in which case one portion of the crystalline matrix functions as a luminescent semiconductor while the second portion is transparent to the light emitted by the first. These conditions are respectively indicated in the figure by labels on the arrowheads denoted as *a* and *b*.

This is a distinct improvement over conventional silicon or germanium transistors which have been noted to produce slight luminescence under similar conditions, since in the instant case the emitted light will not have wave lengths close to the absorption edge of the opposite region, and substantially all of the emitted light will be passed through the non-emitting region without loss.

A further form of the invention may employ semiconductor material having a crystal fault region constituting a distortion within the crystalline matrix. The crystal faults may be either natural or may consist of suitable impurities such as iron, nickel or cobalt. The example of this form of the invention is illustrated in Fig. 6 and includes a natural fault area **330** intermediate conductive contact elements **310** and **320** united at opposite end sections of the matrix. A plurality of regions having a very short average carrier charge lifetime are provided at region **340** within the crystalline matrix by introducing selected impurity activators, as explained previously, into the crystalline matrix. With this construction the region of distortion or crystal fault functions as a region of high rate of minority charge creation and low relative probability of optical recombination, while the region **340** functions as one having a high optical probability of recombination and low rate of minority charge carrier creation. By this innovation it is therefore possible to apply a field across the semiconductor matrix in the manner indicated to sweep the minority charge carriers created in the region of distortion over into the region of high relative probability of optical recombination induced by the presence of the selected activator impurity or impurities to cause light emission due to the recombination of the minority carriers with the majority carriers. Diamonds are an excellent example of this type semiconductor light source.

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An alternative form of the invention according to Fig. 1 may employ a silicon-carbide source **10** prepared as previously described to have a peaked emissive luminescence in the near ultraviolet region, as by an included impurity of thallium between .05 and 1.5% and operated in the manner described with respects to Fig. 3; a diamond photon-modulator **20** prepared or selected to have an absorption edge in the region of 0.3–0.4 micron; and a silicon-carbide phototransistor **30**, prepared in the manner previously described. A particular useful combination will consist of a source **10** and receiver or recorder **30** made from similar valence crystal semiconductors with a different type valence crystal modulator, i. e., germanium-silicon-germanium.

The silicon-carbide light semiconductor is also essentially effective as an all band light source when prepared with trace impurities of plural activators; as for example, thallium, silver, manganese, copper, lead and samarium. However, in this form of the invention the semiconductor should be biased in the reverse direction with a potential of 3–5 volts, and the signal voltage adapted to vary between 1 and 40 volts. In this case the luminescence will be spectrally responsive to the impressed voltage and will vary through bands of orange, yellow, green, blue and violet with the signal voltage. It is therefore possible to use a color sensitive emulsion on the film **140** of Fig. 4 to record distinct color signals proportional to the signal impressed on source **120**.

This embodiment is eminently suitable for translating direct audible signals, as from a microphone, which may be coupled to the signal circuit in the conventional manner, as by a transformer. If desired, the bias may be eliminated and the unit operated with a stepped-up audio signal directly.

It will be obvious that although described with reference to single barriers, all forms of the invention may include plural n-p barriers.

It will further be apparent that the invention is not limited to the specific semiconductor materials used in the previous examples, and may be followed in other known crystalline semiconductors which have a region of lattice distortion or fault or an internal n-p barrier (natural or impurity induced).

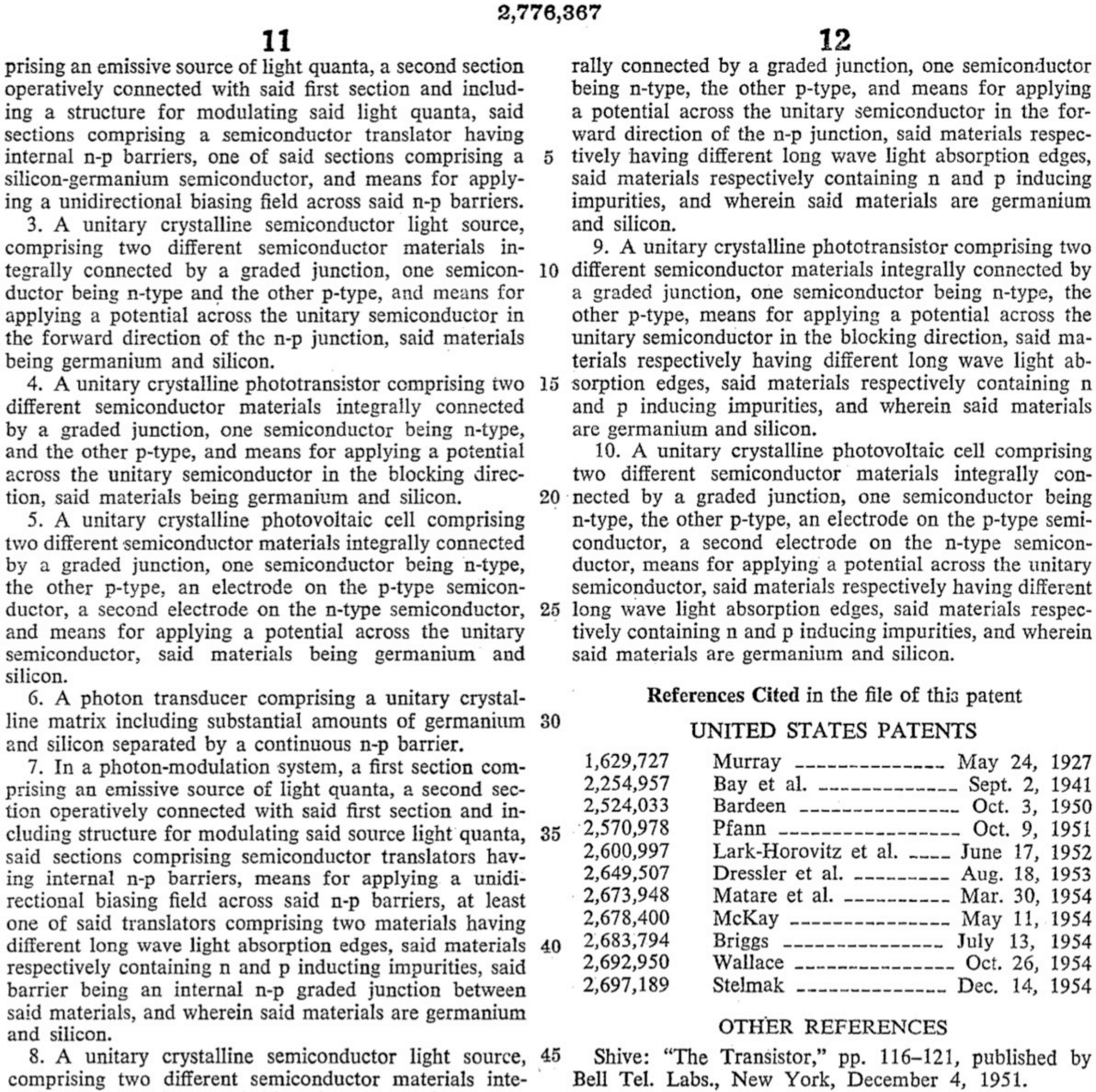
As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope hereof, it is to be understood that the invention is not limited to the specific embodiments hereof, except as defined in the appended claims.

What is claimed is:

1. A photomodulator comprising a unitary crystalline matrix including substantial amounts of germanium and silicon separated by a continuous n-p barrier.

2. In a photon-modulation system, a first section com-

Figure B.221: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



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prising an emissive source of light quanta, a second section operatively connected with said first section and including a structure for modulating said light quanta, said sections comprising a semiconductor translator having internal n-p barriers, one of said sections comprising a silicon-germanium semiconductor, and means for applying a unidirectional biasing field across said n-p barriers.

3. A unitary crystalline semiconductor light source, comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor being n-type and the other p-type, and means for applying a potential across the unitary semiconductor in the forward direction of the n-p junction, said materials being germanium and silicon.

4. A unitary crystalline phototransistor comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor being n-type, and the other p-type, and means for applying a potential across the unitary semiconductor in the blocking direction, said materials being germanium and silicon.

5. A unitary crystalline photovoltaic cell comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor being n-type, the other p-type, an electrode on the p-type semiconductor, a second electrode on the n-type semiconductor, and means for applying a potential across the unitary semiconductor, said materials being germanium and silicon.

6. A photon transducer comprising a unitary crystalline matrix including substantial amounts of germanium and silicon separated by a continuous n-p barrier.

7. In a photon-modulation system, a first section comprising an emissive source of light quanta, a second section operatively connected with said first section and including structure for modulating said source light quanta, said sections comprising semiconductor translators having internal n-p barriers, means for applying a unidirectional biasing field across said n-p barriers, at least one of said translators comprising two materials having different long wave light absorption edges, said materials respectively containing n and p inducting impurities, said barrier being an internal n-p graded junction between said materials, and wherein said materials are germanium and silicon.

8. A unitary crystalline semiconductor light source, comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor

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being n-type, the other p-type, and means for applying a potential across the unitary semiconductor in the forward direction of the n-p junction, said materials respectively having different long wave light absorption edges, said materials respectively containing n and p inducing impurities, and wherein said materials are germanium and silicon.

9. A unitary crystalline phototransistor comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor being n-type, the other p-type, means for applying a potential across the unitary semiconductor in the blocking direction, said materials respectively having different long wave light absorption edges, said materials respectively containing n and p inducing impurities, and wherein said materials are germanium and silicon.

10. A unitary crystalline photovoltaic cell comprising two different semiconductor materials integrally connected by a graded junction, one semiconductor being n-type, the other p-type, an electrode on the p-type semiconductor, a second electrode on the n-type semiconductor, means for applying a potential across the unitary semiconductor, said materials respectively having different long wave light absorption edges, said materials respectively containing n and p inducing impurities, and wherein said materials are germanium and silicon.

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Figure B.222: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).

July 7, 1959 K. LEHOVEC **2,894,145**

DOUBLE MODULATOR UTILIZING PHOTO EMISSIVE MATERIAL

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Fig. 1

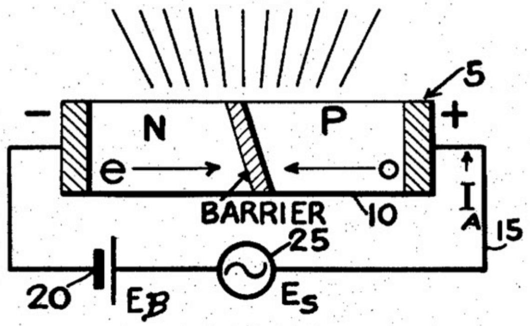


Fig. 2

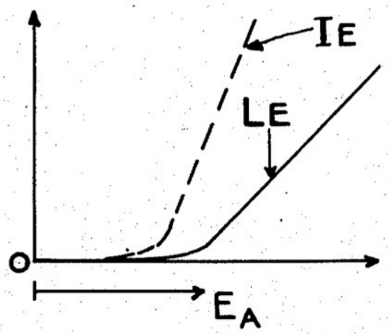


Fig. 3

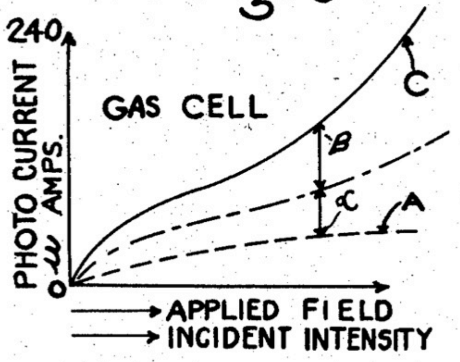
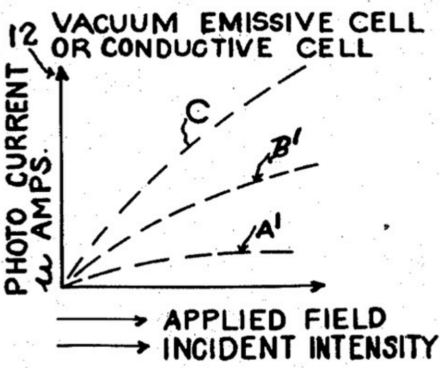
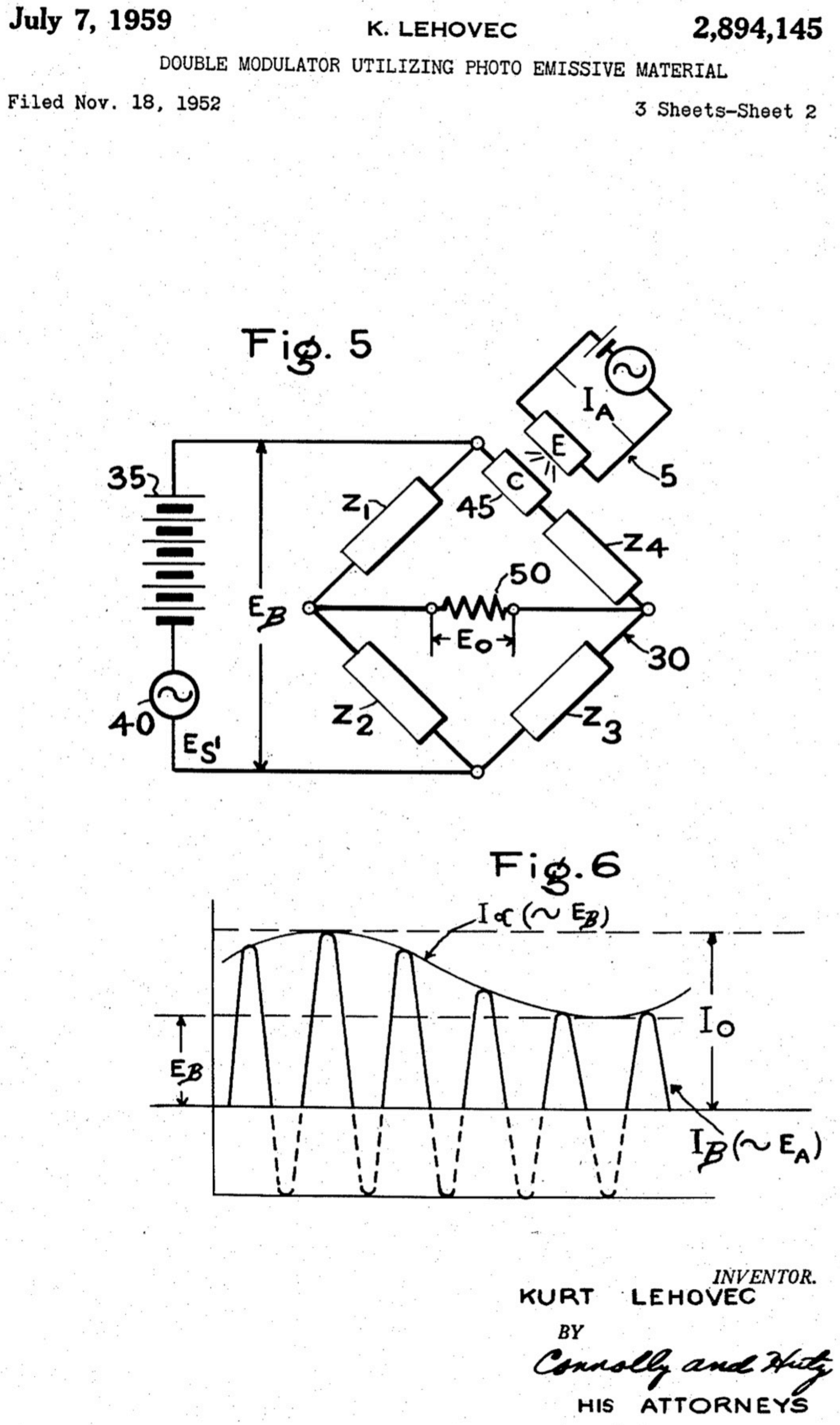


Fig. 4



INVENTOR.
KURT LEHOVEC
BY
Connolly and Hutz
HIS ATTORNEYS

Figure B.223: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



July 7, 1959 K. LEHOVEC **2,894,145**

DOUBLE MODULATOR UTILIZING PHOTO EMISSIVE MATERIAL

Filed Nov. 18, 1952 3 Sheets-Sheet 2

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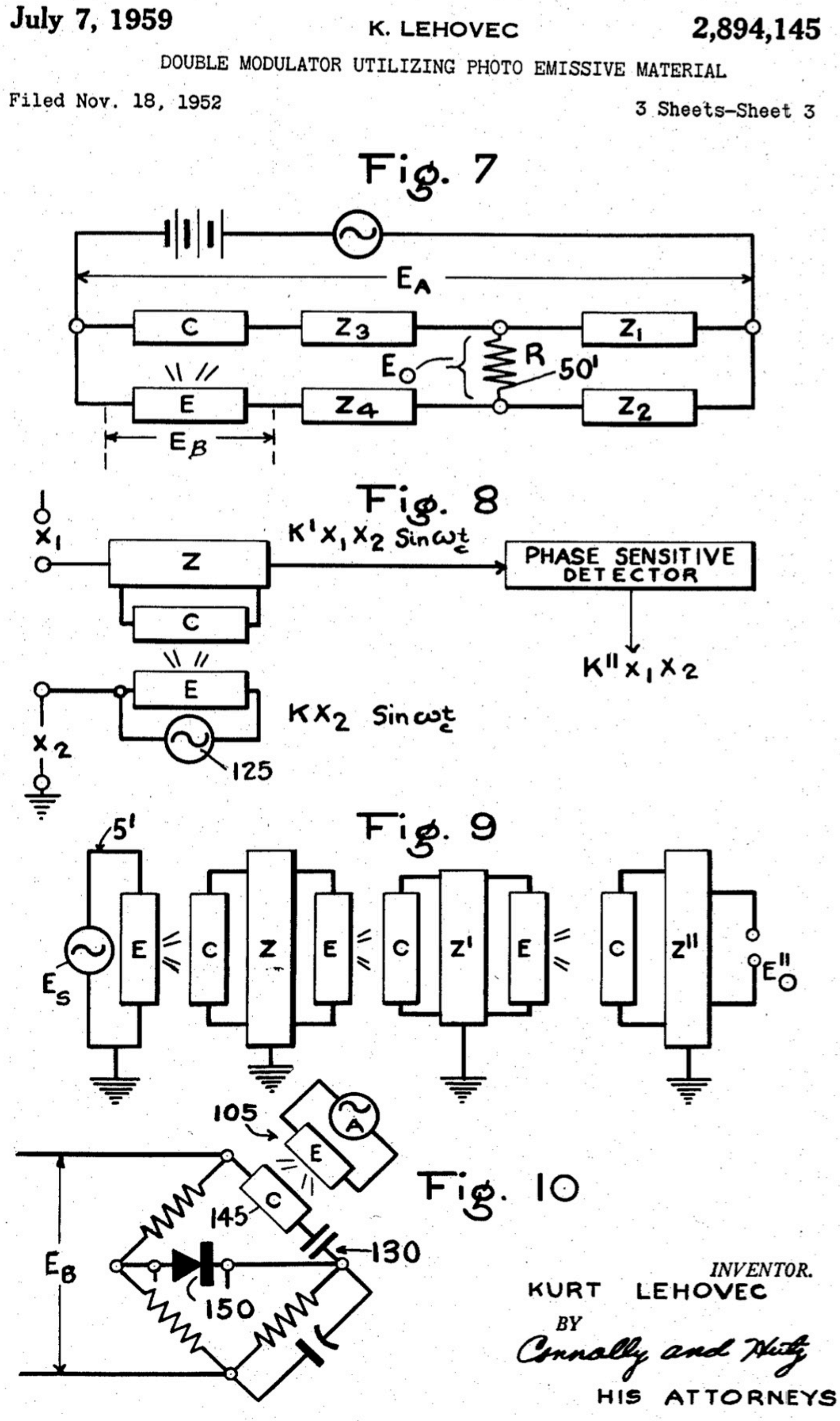
Figure B.224: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



July 7, 1959 K. LEHOVEC **2,894,145**

DOUBLE MODULATOR UTILIZING PHOTO EMISSIVE MATERIAL

Filed Nov. 18, 1952 3 Sheets-Sheet 3

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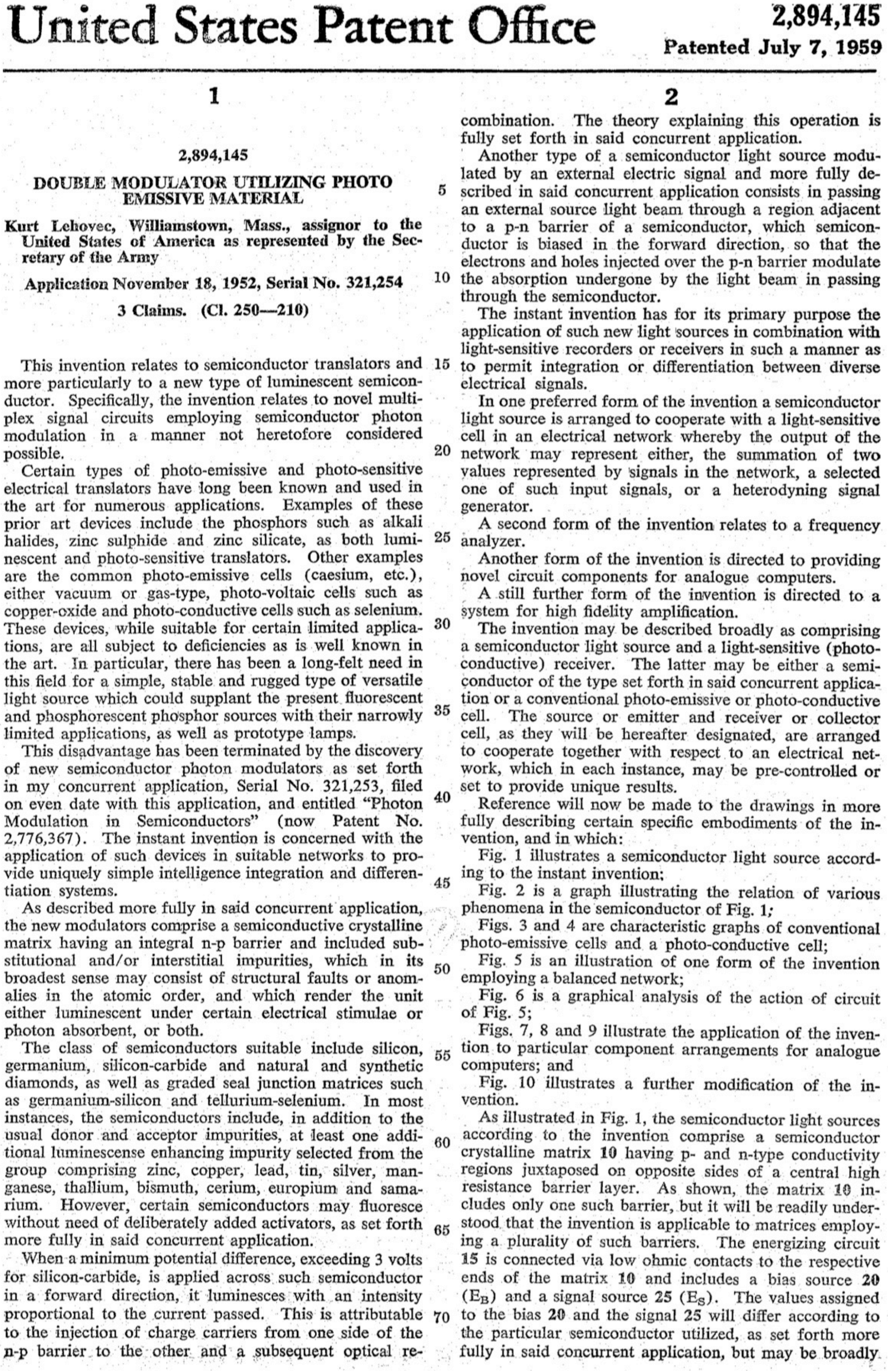
Figure B.225: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



United States Patent Office

2,894,145

Patented July 7, 1959

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DOUBLE MODULATOR UTILIZING PHOTO EMISSIVE MATERIAL

Kurt Lehovec, Williamstown, Mass., assignor to the United States of America as represented by the Secretary of the Army

Application November 18, 1952, Serial No. 321,254

3 Claims. (Cl. 250—210)

This invention relates to semiconductor translators and more particularly to a new type of luminescent semiconductor. Specifically, the invention relates to novel multiplex signal circuits employing semiconductor photon modulation in a manner not heretofore considered possible.

Certain types of photo-emissive and photo-sensitive electrical translators have long been known and used in the art for numerous applications. Examples of these prior art devices include the phosphors such as alkali halides, zinc sulphide and zinc silicate, as both luminescent and photo-sensitive translators. Other examples are the common photo-emissive cells (caesium, etc.), either vacuum or gas-type, photo-voltaic cells such as copper-oxide and photo-conductive cells such as selenium. These devices, while suitable for certain limited applications, are all subject to deficiencies as is well known in the art. In particular, there has been a long-felt need in this field for a simple, stable and rugged type of versatile light source which could supplant the present fluorescent and phosphorescent phosphor sources with their narrowly limited applications, as well as prototype lamps.

This disadvantage has been terminated by the discovery of new semiconductor photon modulators as set forth in my concurrent application, Serial No. 321,253, filed on even date with this application, and entitled "Photon Modulation in Semiconductors" (now Patent No. 2,776,367). The instant invention is concerned with the application of such devices in suitable networks to provide uniquely simple intelligence integration and differentiation systems.

As described more fully in said concurrent application, the new modulators comprise a semiconductive crystalline matrix having an integral n-p barrier and included substitutional and/or interstitial impurities, which in its broadest sense may consist of structural faults or anomalies in the atomic order, and which render the unit either luminescent under certain electrical stimulae or photon absorbent, or both.

The class of semiconductors suitable include silicon, germanium, silicon-carbide and natural and synthetic diamonds, as well as graded seal junction matrices such as germanium-silicon and tellurium-selenium. In most instances, the semiconductors include, in addition to the usual donor and acceptor impurities, at least one additional luminescense enhancing impurity selected from the group comprising zinc, copper, lead, tin, silver, manganese, thallium, bismuth, cerium, europium and samarium. However, certain semiconductors may fluoresce without need of deliberately added activators, as set forth more fully in said concurrent application.

When a minimum potential difference, exceeding 3 volts for silicon-carbide, is applied across such semiconductor in a forward direction, it luminesces with an intensity proportional to the current passed. This is attributable to the injection of charge carriers from one side of the n-p barrier to the other and a subsequent optical recombination. The theory explaining this operation is fully set forth in said concurrent application.

Another type of a semiconductor light source modulated by an external electric signal and more fully described in said concurrent application consists in passing an external source light beam through a region adjacent to a p-n barrier of a semiconductor, which semiconductor is biased in the forward direction, so that the electrons and holes injected over the p-n barrier modulate the absorption undergone by the light beam in passing through the semiconductor.

The instant invention has for its primary purpose the application of such new light sources in combination with light-sensitive recorders or receivers in such a manner as to permit integration or differentiation between diverse electrical signals.

In one preferred form of the invention a semiconductor light source is arranged to cooperate with a light-sensitive cell in an electrical network whereby the output of the network may represent either, the summation of two values represented by signals in the network, a selected one of such input signals, or a heterodyning signal generator.

A second form of the invention relates to a frequency analyzer.

Another form of the invention is directed to providing novel circuit components for analogue computers.

A still further form of the invention is directed to a system for high fidelity amplification.

The invention may be described broadly as comprising a semiconductor light source and a light-sensitive (photo-conductive) receiver. The latter may be either a semiconductor of the type set forth in said concurrent application or a conventional photo-emissive or photo-conductive cell. The source or emitter and receiver or collector cell, as they will be hereafter designated, are arranged to cooperate together with respect to an electrical network, which in each instance, may be pre-controlled or set to provide unique results.

Reference will now be made to the drawings in more fully describing certain specific embodiments of the invention, and in which:

Fig. 1 illustrates a semiconductor light source according to the instant invention;

Fig. 2 is a graph illustrating the relation of various phenomena in the semiconductor of Fig. 1;

Figs. 3 and 4 are characteristic graphs of conventional photo-emissive cells and a photo-conductive cell;

Fig. 5 is an illustration of one form of the invention employing a balanced network;

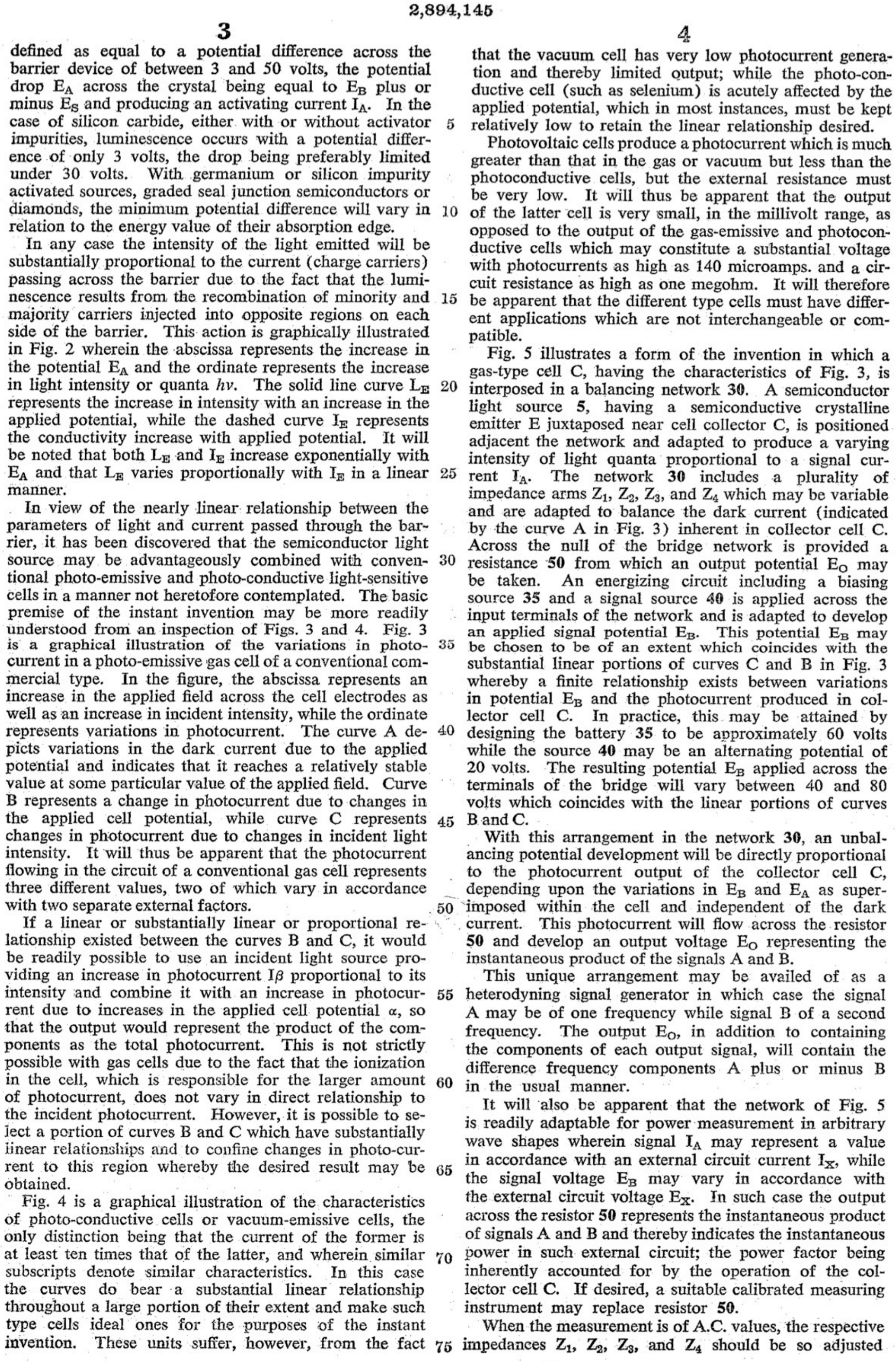
Fig. 6 is a graphical analysis of the action of circuit of Fig. 5;

Figs. 7, 8 and 9 illustrate the application of the invention to particular component arrangements for analogue computers; and

Fig. 10 illustrates a further modification of the invention.

As illustrated in Fig. 1, the semiconductor light sources according to the invention comprise a semiconductor crystalline matrix **10** having p- and n-type conductivity regions juxtaposed on opposite sides of a central high resistance barrier layer. As shown, the matrix **10** includes only one such barrier, but it will be readily understood that the invention is applicable to matrices employing a plurality of such barriers. The energizing circuit **15** is connected via low ohmic contacts to the respective ends of the matrix **10** and includes a bias source **20** (E_B) and a signal source **25** (E_S). The values assigned to the bias **20** and the signal **25** will differ according to the particular semiconductor utilized, as set forth more fully in said concurrent application, but may be broadly

Figure B.226: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



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defined as equal to a potential difference across the barrier device of between 3 and 50 volts, the potential drop E_A across the crystal being equal to E_B plus or minus E_S and producing an activating current I_A. In the case of silicon carbide, either with or without activator impurities, luminescence occurs with a potential difference of only 3 volts, the drop being preferably limited under 30 volts. With germanium or silicon impurity activated sources, graded seal junction semiconductors or diamonds, the minimum potential difference will vary in relation to the energy value of their absorption edge.

In any case the intensity of the light emitted will be substantially proportional to the current (charge carriers) passing across the barrier due to the fact that the luminescence results from the recombination of minority and majority carriers injected into opposite regions on each side of the barrier. This action is graphically illustrated in Fig. 2 wherein the abscissa represents the increase in the potential E_A and the ordinate represents the increase in light intensity or quanta hv. The solid line curve L_E represents the increase in intensity with an increase in the applied potential, while the dashed curve I_E represents the conductivity increase with applied potential. It will be noted that both L_E and I_E increase exponentially with E_A and that L_E varies proportionally with I_E in a linear manner.

In view of the nearly linear relationship between the parameters of light and current passed through the barrier, it has been discovered that the semiconductor light source may be advantageously combined with conventional photo-emissive and photo-conductive light-sensitive cells in a manner not heretofore contemplated. The basic premise of the instant invention may be more readily understood from an inspection of Figs. 3 and 4. Fig. 3 is a graphical illustration of the variations in photocurrent in a photo-emissive gas cell of a conventional commercial type. In the figure, the abscissa represents an increase in the applied field across the cell electrodes as well as an increase in incident intensity, while the ordinate represents variations in photocurrent. The curve A depicts variations in the dark current due to the applied potential and indicates that it reaches a relatively stable value at some particular value of the applied field. Curve B represents a change in photocurrent due to changes in the applied cell potential, while curve C represents changes in photocurrent due to changes in incident light intensity. It will thus be apparent that the photocurrent flowing in the circuit of a conventional gas cell represents three different values, two of which vary in accordance with two separate external factors.

If a linear or substantially linear or proportional relationship existed between the curves B and C, it would be readily possible to use an incident light source providing an increase in photocurrent $I\beta$ proportional to its intensity and combine it with an increase in photocurrent due to increases in the applied cell potential α, so that the output would represent the product of the components as the total photocurrent. This is not strictly possible with gas cells due to the fact that the ionization in the cell, which is responsible for the larger amount of photocurrent, does not vary in direct relationship to the incident photocurrent. However, it is possible to select a portion of curves B and C which have substantially linear relationships and to confine changes in photo-current to this region whereby the desired result may be obtained.

Fig. 4 is a graphical illustration of the characteristics of photo-conductive cells or vacuum-emissive cells, the only distinction being that the current of the former is at least ten times that of the latter, and wherein similar subscripts denote similar characteristics. In this case the curves do bear a substantial linear relationship throughout a large portion of their extent and make such type cells ideal ones for the purposes of the instant invention. These units suffer, however, from the fact

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that the vacuum cell has very low photocurrent generation and thereby limited output; while the photo-conductive cell (such as selenium) is acutely affected by the applied potential, which in most instances, must be kept relatively low to retain the linear relationship desired.

Photovoltaic cells produce a photocurrent which is much greater than that in the gas or vacuum but less than the photoconductive cells, but the external resistance must be very low. It will thus be apparent that the output of the latter cell is very small, in the millivolt range, as opposed to the output of the gas-emissive and photoconductive cells which may constitute a substantial voltage with photocurrents as high as 140 microamps. and a circuit resistance as high as one megohm. It will therefore be apparent that the different type cells must have different applications which are not interchangeable or compatible.

Fig. 5 illustrates a form of the invention in which a gas-type cell C, having the characteristics of Fig. 3, is interposed in a balancing network **30**. A semiconductor light source **5**, having a semiconductive crystalline emitter E juxtaposed near cell collector C, is positioned adjacent the network and adapted to produce a varying intensity of light quanta proportional to a signal current I_A. The network **30** includes a plurality of impedance arms Z_1, Z_2, Z_3, and Z_4 which may be variable and are adapted to balance the dark current (indicated by the curve A in Fig. 3) inherent in collector cell C. Across the null of the bridge network is provided a resistance **50** from which an output potential E_O may be taken. An energizing circuit including a biasing source **35** and a signal source **40** is applied across the input terminals of the network and is adapted to develop an applied signal potential E_B. This potential E_B may be chosen to be of an extent which coincides with the substantial linear portions of curves C and B in Fig. 3 whereby a finite relationship exists between variations in potential E_B and the photocurrent produced in collector cell C. In practice, this may be attained by designing the battery **35** to be approximately 60 volts while the source **40** may be an alternating potential of 20 volts. The resulting potential E_B applied across the terminals of the bridge will vary between 40 and 80 volts which coincides with the linear portions of curves B and C.

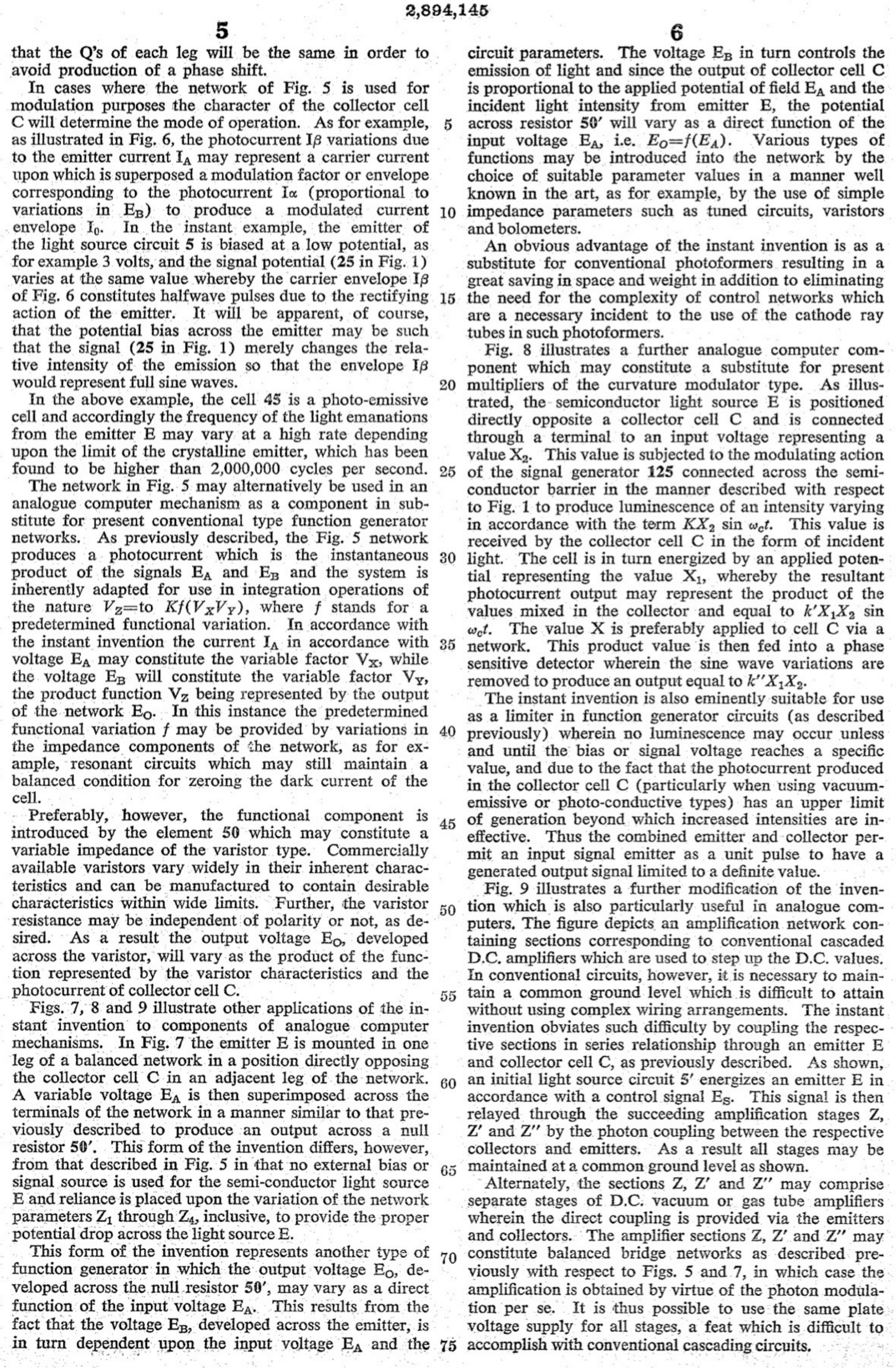
With this arrangement in the network **30**, an unbalancing potential development will be directly proportional to the photocurrent output of the collector cell C, depending upon the variations in E_B and E_A as superimposed within the cell and independent of the dark current. This photocurrent will flow across the resistor **50** and develop an output voltage E_O representing the instantaneous product of the signals A and B.

This unique arrangement may be availed of as a heterodyning signal generator in which case the signal A may be of one frequency while signal B of a second frequency. The output E_O, in addition to containing the components of each output signal, will contain the difference frequency components A plus or minus B in the usual manner.

It will also be apparent that the network of Fig. 5 is readily adaptable for power measurement in arbitrary wave shapes wherein signal I_A may represent a value in accordance with an external circuit current I_X, while the signal voltage E_B may vary in accordance with the external circuit voltage E_X. In such case the output across the resistor **50** represents the instantaneous product of signals A and B and thereby indicates the instantaneous power in such external circuit; the power factor being inherently accounted for by the operation of the collector cell **C**. If desired, a suitable calibrated measuring instrument may replace resistor **50**.

When the measurement is of A.C. values, the respective impedances Z_1, Z_2, Z_3, and Z_4 should be so adjusted

Figure B.227: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



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that the Q's of each leg will be the same in order to avoid production of a phase shift.

In cases where the network of Fig. 5 is used for modulation purposes the character of the collector cell C will determine the mode of operation. As for example, as illustrated in Fig. 6, the photocurrent $I\beta$ variations due to the emitter current I_A may represent a carrier current upon which is superposed a modulation factor or envelope corresponding to the photocurrent $I\alpha$ (proportional to variations in E_B) to produce a modulated current envelope I_0. In the instant example, the emitter of the light source circuit **5** is biased at a low potential, as for example 3 volts, and the signal potential (**25** in Fig. 1) varies at the same value whereby the carrier envelope $I\beta$ of Fig. 6 constitutes halfwave pulses due to the rectifying action of the emitter. It will be apparent, of course, that the potential bias across the emitter may be such that the signal (**25** in Fig. 1) merely changes the relative intensity of the emission so that the envelope $I\beta$ would represent full sine waves.

In the above example, the cell **45** is a photo-emissive cell and accordingly the frequency of the light emanations from the emitter E may vary at a high rate depending upon the limit of the crystalline emitter, which has been found to be higher than 2,000,000 cycles per second.

The network in Fig. 5 may alternatively be used in an analogue computer mechanism as a component in substitute for present conventional type function generator networks. As previously described, the Fig. 5 network produces a photocurrent which is the instantaneous product of the signals E_A and E_B and the system is inherently adapted for use in integration operations of the nature V_Z=to $Kf(V_X V_Y)$, where f stands for a predetermined functional variation. In accordance with the instant invention the current I_A in accordance with voltage E_A may constitute the variable factor V_X, while the voltage E_B will constitute the variable factor V_Y, the product function V_Z being represented by the output of the network E_O. In this instance the predetermined functional variation f may be provided by variations in the impedance components of the network, as for example, resonant circuits which may still maintain a balanced condition for zeroing the dark current of the cell.

Preferably, however, the functional component is introduced by the element **50** which may constitute a variable impedance of the varistor type. Commercially available varistors vary widely in their inherent characteristics and can be manufactured to contain desirable characteristics within wide limits. Further, the varistor resistance may be independent of polarity or not, as desired. As a result the output voltage E_O, developed across the varistor, will vary as the product of the function represented by the varistor characteristics and the photocurrent of collector cell C.

Figs. 7, 8 and 9 illustrate other applications of the instant invention to components of analogue computer mechanisms. In Fig. 7 the emitter E is mounted in one leg of a balanced network in a position directly opposing the collector cell C in an adjacent leg of the network. A variable voltage E_A is then superimposed across the terminals of the network in a manner similar to that previously described to produce an output across a null resistor **50'**. This form of the invention differs, however, from that described in Fig. 5 in that no external bias or signal source is used for the semi-conductor light source E and reliance is placed upon the variation of the network parameters Z_1 through Z_4, inclusive, to provide the proper potential drop across the light source E.

This form of the invention represents another type of function generator in which the output voltage E_O, developed across the null resistor **50'**, may vary as a direct function of the input voltage E_A. This results from the fact that the voltage E_B, developed across the emitter, is in turn dependent upon the input voltage E_A and the circuit parameters. The voltage E_B in turn controls the emission of light and since the output of collector cell C is proportional to the applied potential of field E_A and the incident light intensity from emitter E, the potential across resistor **50'** will vary as a direct function of the input voltage E_A, i.e. $E_O=f(E_A)$. Various types of functions may be introduced into the network by the choice of suitable parameter values in a manner well known in the art, as for example, by the use of simple impedance parameters such as tuned circuits, varistors and bolometers.

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An obvious advantage of the instant invention is as a substitute for conventional photoformers resulting in a great saving in space and weight in addition to eliminating the need for the complexity of control networks which are a necessary incident to the use of the cathode ray tubes in such photoformers.

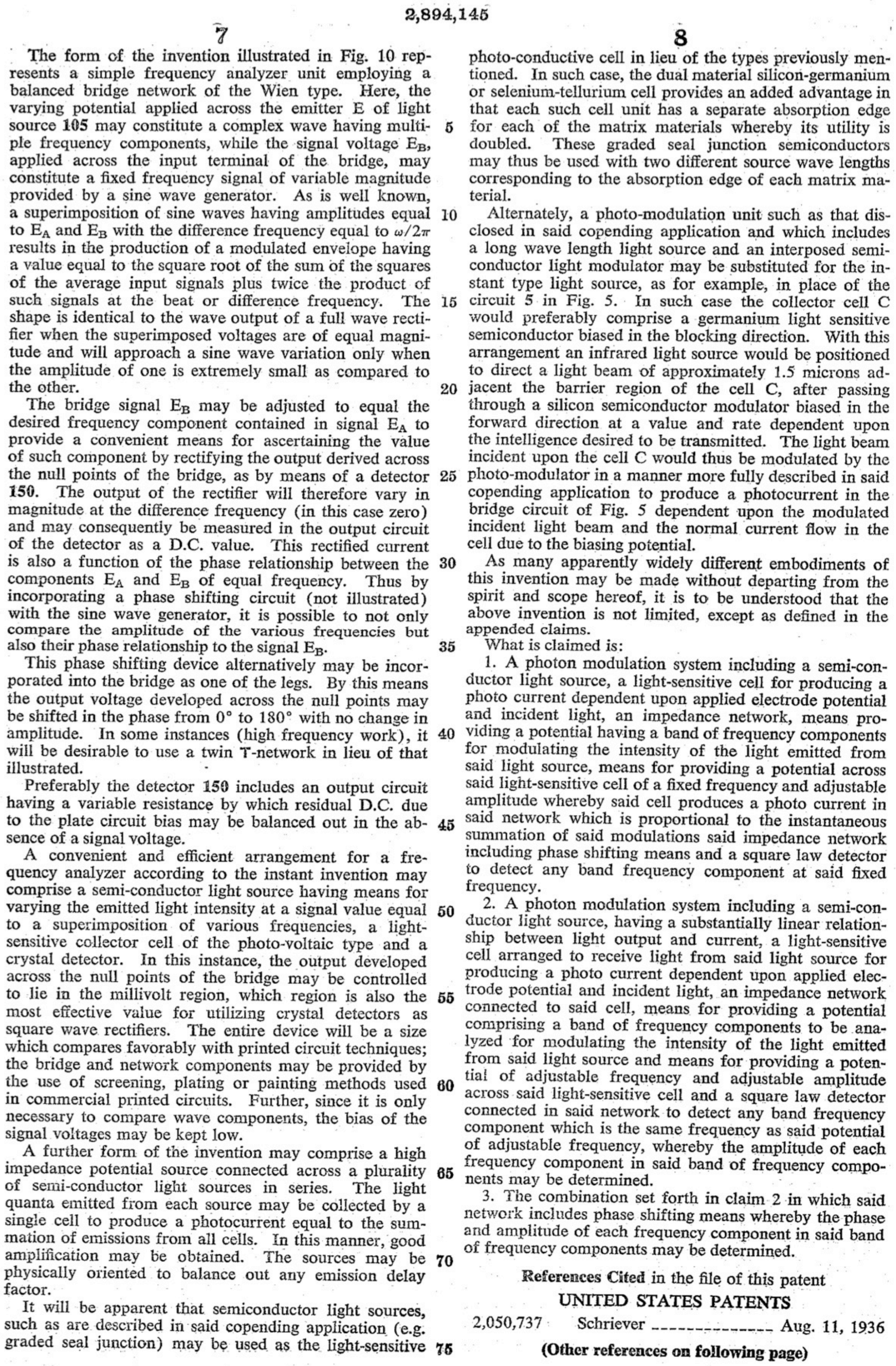
Fig. 8 illustrates a further analogue computer component which may constitute a substitute for present multipliers of the curvature modulator type. As illustrated, the semiconductor light source E is positioned directly opposite a collector cell C and is connected through a terminal to an input voltage representing a value X_2. This value is subjected to the modulating action of the signal generator **125** connected across the semiconductor barrier in the manner described with respect to Fig. 1 to produce luminescence of an intensity varying in accordance with the term $KX_2 \sin \omega_c t$. This value is received by the collector cell C in the form of incident light. The cell is in turn energized by an applied potential representing the value X_1, whereby the resultant photocurrent output may represent the product of the values mixed in the collector and equal to $k'X_1X_2 \sin \omega_c t$. The value X is preferably applied to cell C via a network. This product value is then fed into a phase sensitive detector wherein the sine wave variations are removed to produce an output equal to $k''X_1X_2$.

The instant invention is also eminently suitable for use as a limiter in function generator circuits (as described previously) wherein no luminescence may occur unless and until the bias or signal voltage reaches a specific value, and due to the fact that the photocurrent produced in the collector cell C (particularly when using vacuum-emissive or photo-conductive types) has an upper limit of generation beyond which increased intensities are ineffective. Thus the combined emitter and collector permit an input signal emitter as a unit pulse to have a generated output signal limited to a definite value.

Fig. 9 illustrates a further modification of the invention which is also particularly useful in analogue computers. The figure depicts an amplification network containing sections corresponding to conventional cascaded D.C. amplifiers which are used to step up the D.C. values. In conventional circuits, however, it is necessary to maintain a common ground level which is difficult to attain without using complex wiring arrangements. The instant invention obviates such difficulty by coupling the respective sections in series relationship through an emitter E and collector cell C, as previously described. As shown, an initial light source circuit **5'** energizes an emitter E in accordance with a control signal E_S. This signal is then relayed through the succeeding amplification stages Z, Z' and Z'' by the photon coupling between the respective collectors and emitters. As a result all stages may be maintained at a common ground level as shown.

Alternately, the sections Z, Z' and Z'' may comprise separate stages of D.C. vacuum or gas tube amplifiers wherein the direct coupling is provided via the emitters and collectors. The amplifier sections Z, Z' and Z'' may constitute balanced bridge networks as described previously with respect to Figs. 5 and 7, in which case the amplification is obtained by virtue of the photon modulation per se. It is thus possible to use the same plate voltage supply for all stages, a feat which is difficult to accomplish with conventional cascading circuits.

Figure B.228: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).



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The form of the invention illustrated in Fig. 10 represents a simple frequency analyzer unit employing a balanced bridge network of the Wien type. Here, the varying potential applied across the emitter E of light source **105** may constitute a complex wave having multiple frequency components, while the signal voltage E_B, applied across the input terminal of the bridge, may constitute a fixed frequency signal of variable magnitude provided by a sine wave generator. As is well known, a superimposition of sine waves having amplitudes equal to E_A and E_B with the difference frequency equal to $\omega/2\pi$ results in the production of a modulated envelope having a value equal to the square root of the sum of the squares of the average input signals plus twice the product of such signals at the beat or difference frequency. The shape is identical to the wave output of a full wave rectifier when the superimposed voltages are of equal magnitude and will approach a sine wave variation only when the amplitude of one is extremely small as compared to the other.

The bridge signal E_B may be adjusted to equal the desired frequency component contained in signal E_A to provide a convenient means for ascertaining the value of such component by rectifying the output derived across the null points of the bridge, as by means of a detector **150**. The output of the rectifier will therefore vary in magnitude at the difference frequency (in this case zero) and may consequently be measured in the output circuit of the detector as a D.C. value. This rectified current is also a function of the phase relationship between the components E_A and E_B of equal frequency. Thus by incorporating a phase shifting circuit (not illustrated) with the sine wave generator, it is possible to not only compare the amplitude of the various frequencies but also their phase relationship to the signal E_B.

This phase shifting device alternatively may be incorporated into the bridge as one of the legs. By this means the output voltage developed across the null points may be shifted in the phase from 0° to 180° with no change in amplitude. In some instances (high frequency work), it will be desirable to use a twin T-network in lieu of that illustrated.

Preferably the detector **150** includes an output circuit having a variable resistance by which residual D.C. due to the plate circuit bias may be balanced out in the absence of a signal voltage.

A convenient and efficient arrangement for a frequency analyzer according to the instant invention may comprise a semi-conductor light source having means for varying the emitted light intensity at a signal value equal to a superimposition of various frequencies, a light-sensitive collector cell of the photo-voltaic type and a crystal detector. In this instance, the output developed across the null points of the bridge may be controlled to lie in the millivolt region, which region is also the most effective value for utilizing crystal detectors as square wave rectifiers. The entire device will be a size which compares favorably with printed circuit techniques; the bridge and network components may be provided by the use of screening, plating or painting methods used in commercial printed circuits. Further, since it is only necessary to compare wave components, the bias of the signal voltages may be kept low.

A further form of the invention may comprise a high impedance potential source connected across a plurality of semi-conductor light sources in series. The light quanta emitted from each source may be collected by a single cell to produce a photocurrent equal to the summation of emissions from all cells. In this manner, good amplification may be obtained. The sources may be physically oriented to balance out any emission delay factor.

It will be apparent that semiconductor light sources, such as are described in said copending application (e.g. graded seal junction) may be used as the light-sensitive photo-conductive cell in lieu of the types previously mentioned. In such case, the dual material silicon-germanium or selenium-tellurium cell provides an added advantage in that each such cell unit has a separate absorption edge for each of the matrix materials whereby its utility is doubled. These graded seal junction semiconductors may thus be used with two different source wave lengths corresponding to the absorption edge of each matrix material.

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Alternately, a photo-modulation unit such as that disclosed in said copending application and which includes a long wave length light source and an interposed semiconductor light modulator may be substituted for the instant type light source, as for example, in place of the circuit 5 in Fig. 5. In such case the collector cell C would preferably comprise a germanium light sensitive semiconductor biased in the blocking direction. With this arrangement an infrared light source would be positioned to direct a light beam of approximately 1.5 microns adjacent the barrier region of the cell C, after passing through a silicon semiconductor modulator biased in the forward direction at a value and rate dependent upon the intelligence desired to be transmitted. The light beam incident upon the cell C would thus be modulated by the photo-modulator in a manner more fully described in said copending application to produce a photocurrent in the bridge circuit of Fig. 5 dependent upon the modulated incident light beam and the normal current flow in the cell due to the biasing potential.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope hereof, it is to be understood that the above invention is not limited, except as defined in the appended claims.

What is claimed is:

1. A photon modulation system including a semi-conductor light source, a light-sensitive cell for producing a photo current dependent upon applied electrode potential and incident light, an impedance network, means providing a potential having a band of frequency components for modulating the intensity of the light emitted from said light source, means for providing a potential across said light-sensitive cell of a fixed frequency and adjustable amplitude whereby said cell produces a photo current in said network which is proportional to the instantaneous summation of said modulations said impedance network including phase shifting means and a square law detector to detect any band frequency component at said fixed frequency.

2. A photon modulation system including a semi-conductor light source, having a substantially linear relationship between light output and current, a light-sensitive cell arranged to receive light from said light source for producing a photo current dependent upon applied electrode potential and incident light, an impedance network connected to said cell, means for providing a potential comprising a band of frequency components to be analyzed for modulating the intensity of the light emitted from said light source and means for providing a potential of adjustable frequency and adjustable amplitude across said light-sensitive cell and a square law detector connected in said network to detect any band frequency component which is the same frequency as said potential of adjustable frequency, whereby the amplitude of each frequency component in said band of frequency components may be determined.

3. The combination set forth in claim 2 in which said network includes phase shifting means whereby the phase and amplitude of each frequency component in said band of frequency components may be determined.

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Figure B.229: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).

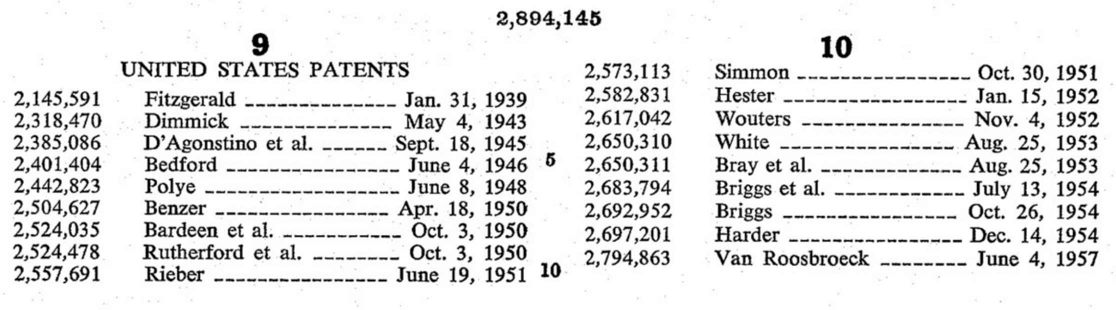

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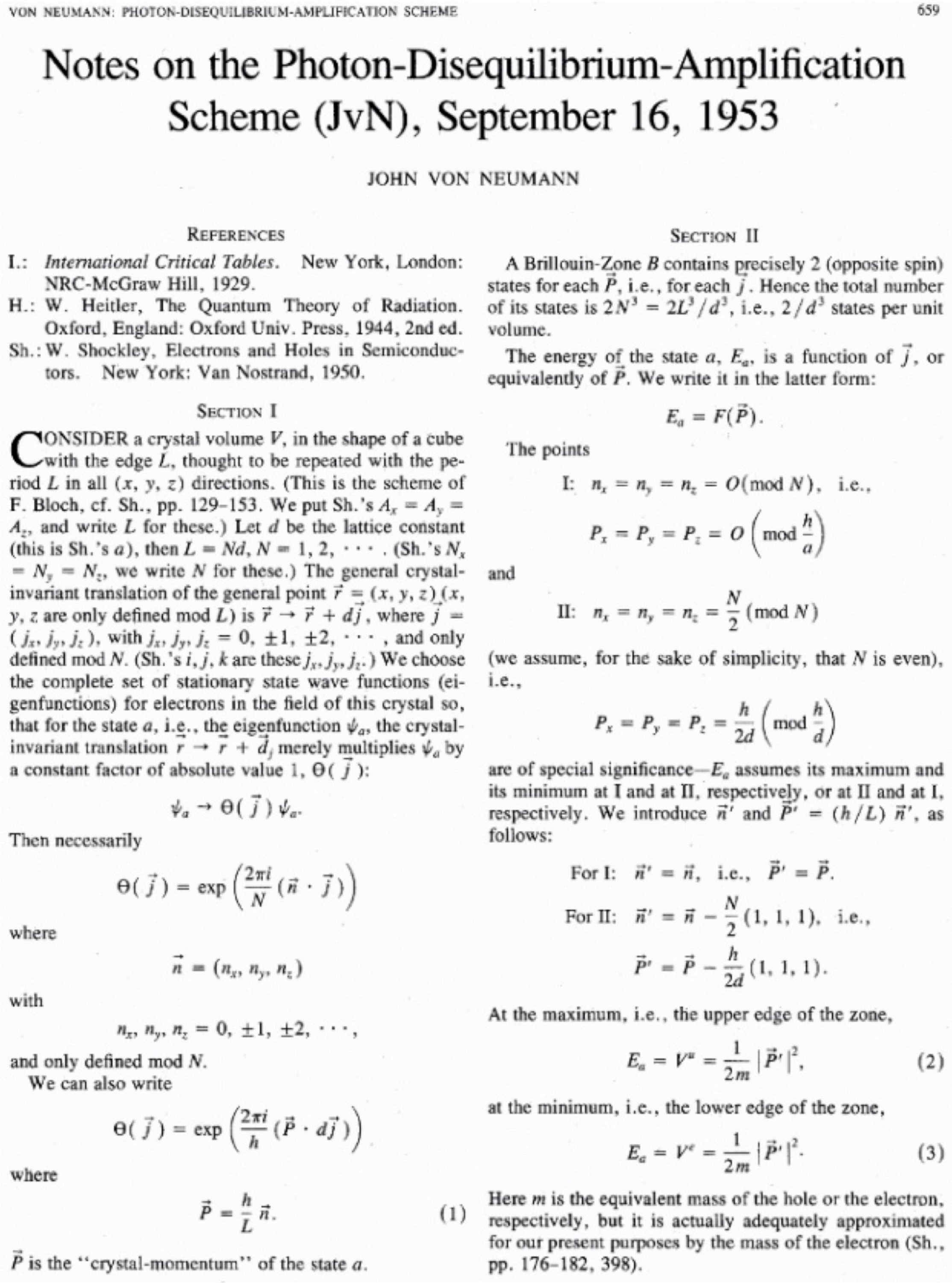
Figure B.230: Kurt Lehovec worked under Bernhard Gudden during World War II, was extensively interrogated by and came to the United States after the war, and filed detailed patent applications on improved LEDs (possibly based on wartime work).

John von Neuman (1903–1957) made a detailed proposal for laser diodes in 1953, which was likely circulated via his many consulting roles [*IEEE Journal of Quantum Electronics* 23:6:659–673 (1987)]



Notes on the Photon-Disequilibrium-Amplification Scheme (JvN), September 16, 1953

JOHN VON NEUMANN

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SECTION I

CONSIDER a crystal volume V, in the shape of a cube with the edge L, thought to be repeated with the period L in all (x, y, z) directions. (This is the scheme of F. Bloch, cf. Sh., pp. 129–153. We put Sh.'s $A_x = A_y = A_z$, and write L for these.) Let d be the lattice constant (this is Sh.'s a), then $L = Nd$, $N = 1, 2, \cdots$. (Sh.'s $N_x = N_y = N_z$, we write N for these.) The general crystal-invariant translation of the general point $\vec{r} = (x, y, z)$ (x, y, z are only defined mod L) is $\vec{r} \rightarrow \vec{r} + d\vec{j}$, where $\vec{j} = (j_x, j_y, j_z)$, with $j_x, j_y, j_z = 0, \pm 1, \pm 2, \cdots$, and only defined mod N. (Sh.'s i, j, k are these j_x, j_y, j_z.) We choose the complete set of stationary state wave functions (eigenfunctions) for electrons in the field of this crystal so, that for the state a, i.e., the eigenfunction ψ_a, the crystal-invariant translation $\vec{r} \rightarrow \vec{r} + \vec{d}_j$ merely multiplies ψ_a by a constant factor of absolute value 1, $\Theta(\vec{j})$:

$$\psi_a \rightarrow \Theta(\vec{j})\,\psi_a.$$

Then necessarily

$$\Theta(\vec{j}) = \exp\left(\frac{2\pi i}{N}(\vec{n} \cdot \vec{j})\right)$$

where

$$\vec{n} = (n_x, n_y, n_z)$$

with

$$n_x, n_y, n_z = 0, \pm 1, \pm 2, \cdots,$$

and only defined mod N.

We can also write

$$\Theta(\vec{j}) = \exp\left(\frac{2\pi i}{h}(\vec{P} \cdot d\vec{j})\right)$$

where

$$\vec{P} = \frac{h}{L}\,\vec{n}. \tag{1}$$

$\vec{P}$ is the "crystal-momentum" of the state a.

SECTION II

A Brillouin-Zone B contains precisely 2 (opposite spin) states for each $\vec{P}$, i.e., for each $\vec{j}$. Hence the total number of its states is $2N^3 = 2L^3/d^3$, i.e., $2/d^3$ states per unit volume.

The energy of the state a, E_a, is a function of $\vec{j}$, or equivalently of $\vec{P}$. We write it in the latter form:

$$E_a = F(\vec{P}).$$

The points

$$\text{I:}\quad n_x = n_y = n_z = O(\text{mod } N), \quad \text{i.e.,}$$

$$P_x = P_y = P_z = O\left(\text{mod } \frac{h}{a}\right)$$

and

$$\text{II:}\quad n_x = n_y = n_z = \frac{N}{2}(\text{mod } N)$$

(we assume, for the sake of simplicity, that N is even), i.e.,

$$P_x = P_y = P_z = \frac{h}{2d}\left(\text{mod } \frac{h}{d}\right)$$

are of special significance—E_a assumes its maximum and its minimum at I and at II, respectively, or at II and at I, respectively. We introduce $\vec{n}'$ and $\vec{P}' = (h/L)\,\vec{n}'$, as follows:

$$\text{For I:}\quad \vec{n}' = \vec{n}, \quad \text{i.e.,} \quad \vec{P}' = \vec{P}.$$

$$\text{For II:}\quad \vec{n}' = \vec{n} - \frac{N}{2}(1, 1, 1), \quad \text{i.e.,}$$

$$\vec{P}' = \vec{P} - \frac{h}{2d}(1, 1, 1).$$

At the maximum, i.e., the upper edge of the zone,

$$E_a = V^u = \frac{1}{2m}|\vec{P}'|^2, \tag{2}$$

at the minimum, i.e., the lower edge of the zone,

$$E_a = V^e = \frac{1}{2m}|\vec{P}'|^2. \tag{3}$$

Here m is the equivalent mass of the hole or the electron, respectively, but it is actually adequately approximated for our present purposes by the mass of the electron (Sh., pp. 176–182, 398).

Figure B.231: John von Neumann made a detailed proposal for laser diodes in 1953, which was likely circulated via his many consulting roles in government and industry [*IEEE Journal of Quantum Electronics* 23:6:659–673 (1987)].

Feb. 11, 1964 **W. HEYWANG** **3,121,203**

SEMICONDUCTOR MASER WITH MODULATING MEANS

Filed April 22, 1959 2 Sheets-Sheet 1

Fig.1

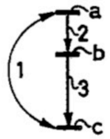


Fig.2a

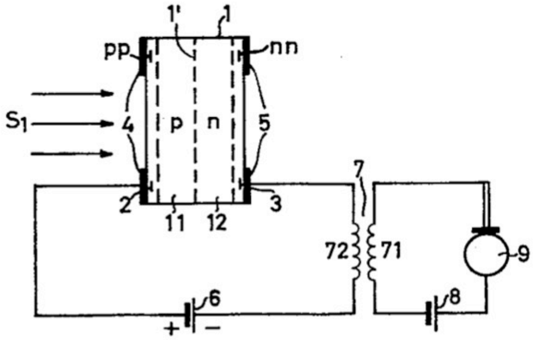


Fig.2b

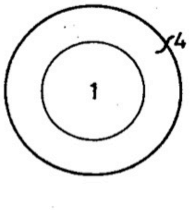


Fig.3

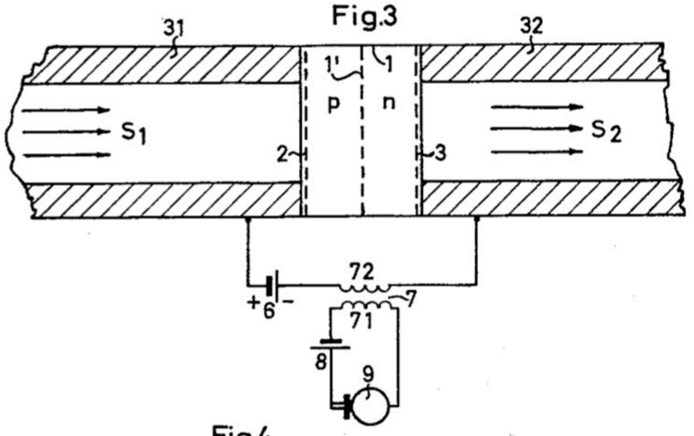
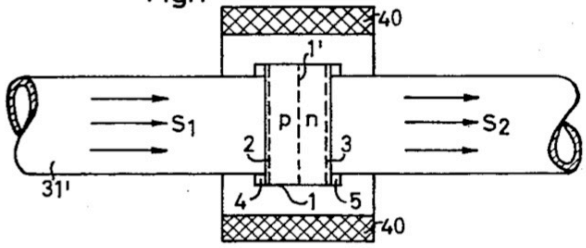


Fig.4



Inventor:
Walter Heywang.
By. Atty.

Figure B.232: Walter Heywang filed detailed patent applications on laser diodes in 1958.

Feb. 11, 1964 **W. HEYWANG** **3,121,203**

SEMICONDUCTOR MASER WITH MODULATING MEANS

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Fig.5

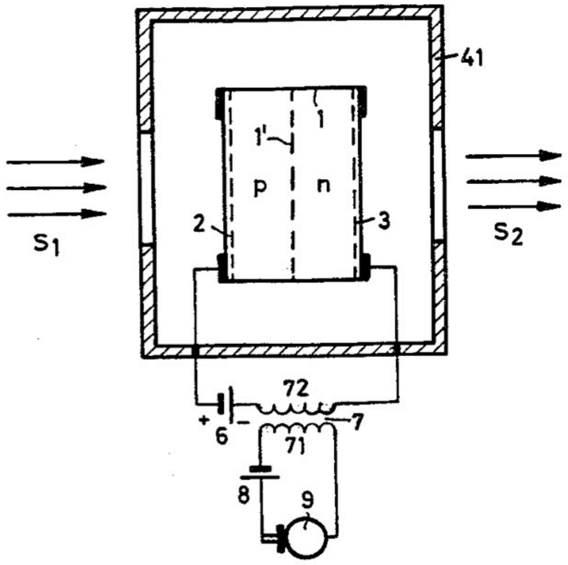
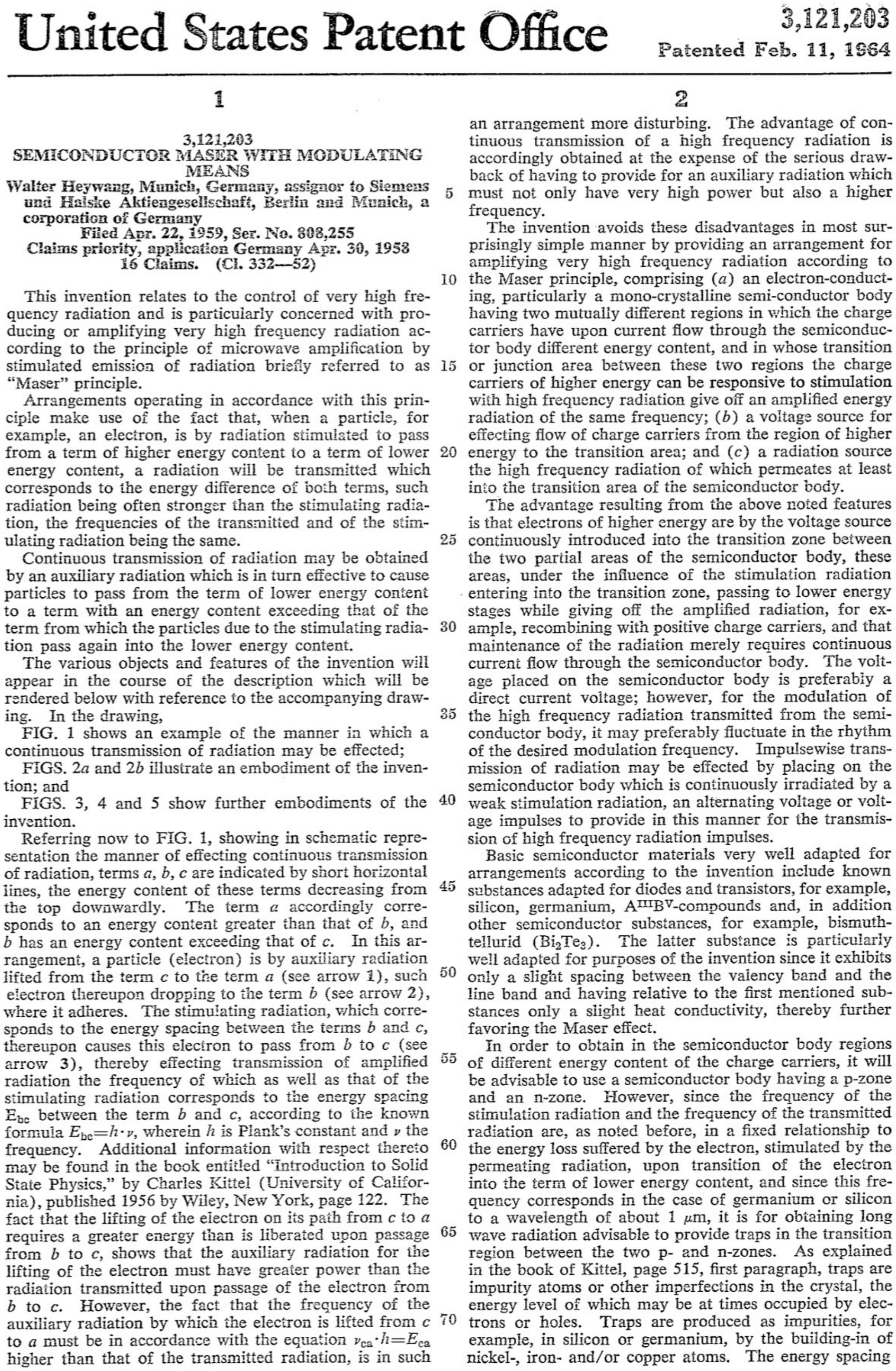


Figure B.233: Walter Heywang filed detailed patent applications on laser diodes in 1958.



United States Patent Office

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Patented Feb. 11, 1964

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SEMICONDUCTOR MASER WITH MODULATING MEANS

Walter Heywang, Munich, Germany, assignor to Siemens und Halske Aktiengesellschaft, Berlin and Munich, a corporation of Germany

Filed Apr. 22, 1959, Ser. No. 808,255
Claims priority, application Germany Apr. 30, 1958
16 Claims. (Cl. 332—52)

This invention relates to the control of very high frequency radiation and is particularly concerned with producing or amplifying very high frequency radiation according to the principle of microwave amplification by stimulated emission of radiation briefly referred to as "Maser" principle.

Arrangements operating in accordance with this principle make use of the fact that, when a particle, for example, an electron, is by radiation stimulated to pass from a term of higher energy content to a term of lower energy content, a radiation will be transmitted which corresponds to the energy difference of both terms, such radiation being often stronger than the stimulating radiation, the frequencies of the transmitted and of the stimulating radiation being the same.

Continuous transmission of radiation may be obtained by an auxiliary radiation which is in turn effective to cause particles to pass from the term of lower energy content to a term with an energy content exceeding that of the term from which the particles due to the stimulating radiation pass again into the lower energy content.

The various objects and features of the invention will appear in the course of the description which will be rendered below with reference to the accompanying drawing. In the drawing,

FIG. 1 shows an example of the manner in which a continuous transmission of radiation may be effected;

FIGS. 2*a* and 2*b* illustrate an embodiment of the invention; and

FIGS. 3, 4 and 5 show further embodiments of the invention.

Referring now to FIG. 1, showing in schematic representation the manner of effecting continuous transmission of radiation, terms *a*, *b*, *c* are indicated by short horizontal lines, the energy content of these terms decreasing from the top downwardly. The term *a* accordingly corresponds to an energy content greater than that of *b*, and *b* has an energy content exceeding that of *c*. In this arrangement, a particle (electron) is by auxiliary radiation lifted from the term *c* to the term *a* (see arrow 1), such electron thereupon dropping to the term *b* (see arrow 2), where it adheres. The stimulating radiation, which corresponds to the energy spacing between the terms *b* and *c*, thereupon causes this electron to pass from *b* to *c* (see arrow 3), thereby effecting transmission of amplified radiation the frequency of which as well as that of the stimulating radiation corresponds to the energy spacing E_{bc} between the term *b* and *c*, according to the known formula $E_{bc}=h\cdot\nu$, wherein h is Plank's constant and ν the frequency. Additional information with respect thereto may be found in the book entitled "Introduction to Solid State Physics," by Charles Kittel (University of California), published 1956 by Wiley, New York, page 122. The fact that the lifting of the electron on its path from *c* to *a* requires a greater energy than is liberated upon passage from *b* to *c*, shows that the auxiliary radiation for the lifting of the electron must have greater power than the radiation transmitted upon passage of the electron from *b* to *c*. However, the fact that the frequency of the auxiliary radiation by which the electron is lifted from *c* to *a* must be in accordance with the equation $\nu_{ca}\cdot h=E_{ca}$ higher than that of the transmitted radiation, is in such an arrangement more disturbing. The advantage of continuous transmission of a high frequency radiation is accordingly obtained at the expense of the serious drawback of having to provide for an auxiliary radiation which must not only have very high power but also a higher frequency.

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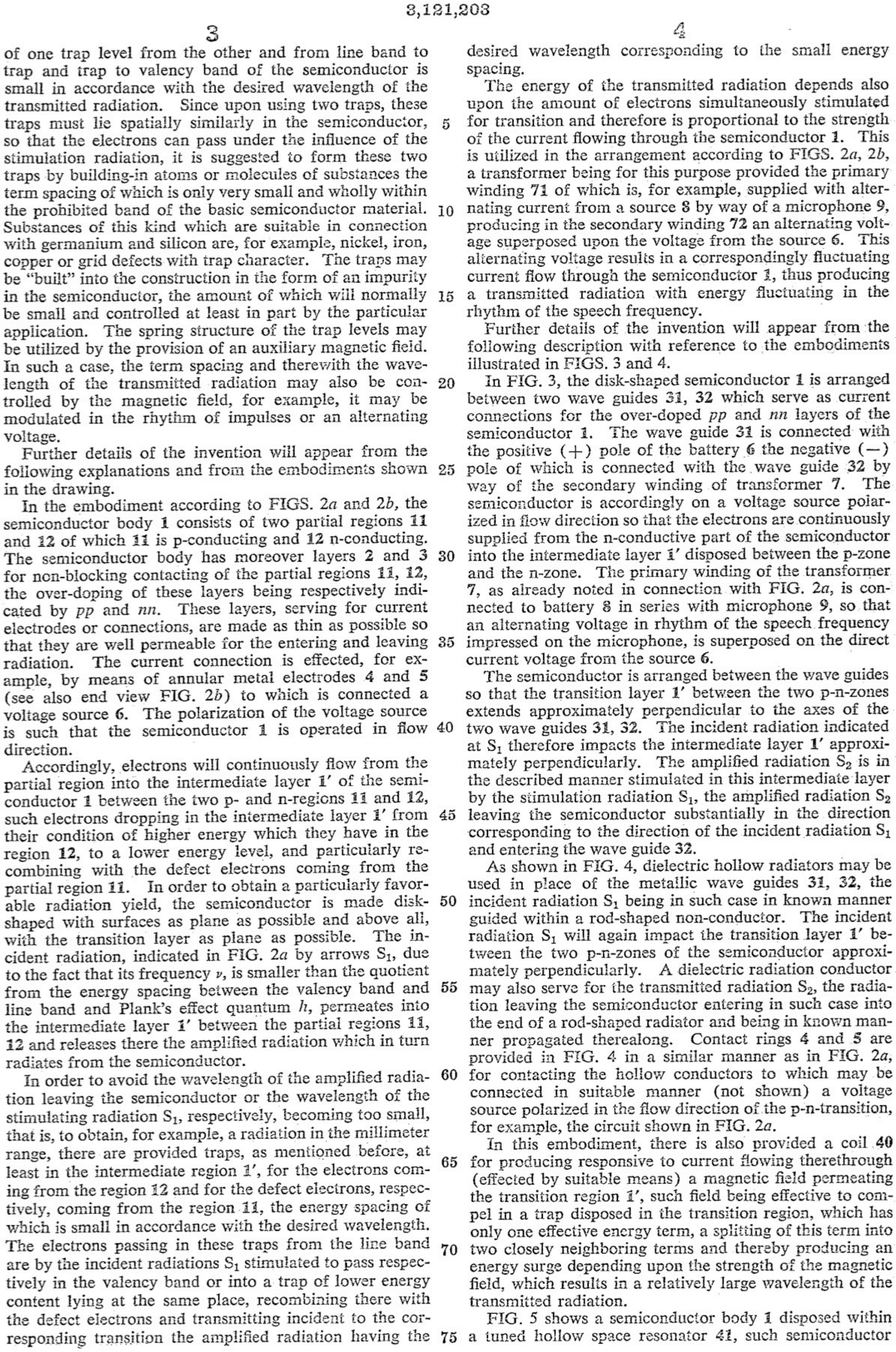
The invention avoids these disadvantages in most surprisingly simple manner by providing an arrangement for amplifying very high frequency radiation according to the Maser principle, comprising (*a*) an electron-conducting, particularly a mono-crystalline semi-conductor body having two mutually different regions in which the charge carriers have upon current flow through the semiconductor body different energy content, and in whose transition or junction area between these two regions the charge carriers of higher energy can be responsive to stimulation with high frequency radiation give off an amplified energy radiation of the same frequency; (*b*) a voltage source for effecting flow of charge carriers from the region of higher energy to the transition area; and (*c*) a radiation source the high frequency radiation of which permeates at least into the transition area of the semiconductor body.

The advantage resulting from the above noted features is that electrons of higher energy are by the voltage source continuously introduced into the transition zone between the two partial areas of the semiconductor body, these areas, under the influence of the stimulation radiation entering into the transition zone, passing to lower energy stages while giving off the amplified radiation, for example, recombining with positive charge carriers, and that maintenance of the radiation merely requires continuous current flow through the semiconductor body. The voltage placed on the semiconductor body is preferably a direct current voltage; however, for the modulation of the high frequency radiation transmitted from the semiconductor body, it may preferably fluctuate in the rhythm of the desired modulation frequency. Impulsewise transmission of radiation may be effected by placing on the semiconductor body which is continuously irradiated by a weak stimulation radiation, an alternating voltage or voltage impulses to provide in this manner for the transmission of high frequency radiation impulses.

Basic semiconductor materials very well adapted for arrangements according to the invention include known substances adapted for diodes and transistors, for example, silicon, germanium, $A^{III}B^{V}$-compounds and, in addition other semiconductor substances, for example, bismuth-tellurid (Bi_2Te_3). The latter substance is particularly well adapted for purposes of the invention since it exhibits only a slight spacing between the valency band and the line band and having relative to the first mentioned substances only a slight heat conductivity, thereby further favoring the Maser effect.

In order to obtain in the semiconductor body regions of different energy content of the charge carriers, it will be advisable to use a semiconductor body having a p-zone and an n-zone. However, since the frequency of the stimulation radiation and the frequency of the transmitted radiation are, as noted before, in a fixed relationship to the energy loss suffered by the electron, stimulated by the permeating radiation, upon transition of the electron into the term of lower energy content, and since this frequency corresponds in the case of germanium or silicon to a wavelength of about 1 μm, it is for obtaining long wave radiation advisable to provide traps in the transition region between the two p- and n-zones. As explained in the book of Kittel, page 515, first paragraph, traps are impurity atoms or other imperfections in the crystal, the energy level of which may be at times occupied by electrons or holes. Traps are produced as impurities, for example, in silicon or germanium, by the building-in of nickel-, iron- and/or copper atoms. The energy spacing

Figure B.234: Walter Heywang filed detailed patent applications on laser diodes in 1958.



of one trap level from the other and from line band to trap and trap to valency band of the semiconductor is small in accordance with the desired wavelength of the transmitted radiation. Since upon using two traps, these traps must lie spatially similarly in the semiconductor, so that the electrons can pass under the influence of the stimulation radiation, it is suggested to form these two traps by building-in atoms or molecules of substances the term spacing of which is only very small and wholly within the prohibited band of the basic semiconductor material. Substances of this kind which are suitable in connection with germanium and silicon are, for example, nickel, iron, copper or grid defects with trap character. The traps may be "built" into the construction in the form of an impurity in the semiconductor, the amount of which will normally be small and controlled at least in part by the particular application. The spring structure of the trap levels may be utilized by the provision of an auxiliary magnetic field. In such a case, the term spacing and therewith the wavelength of the transmitted radiation may also be controlled by the magnetic field, for example, it may be modulated in the rhythm of impulses or an alternating voltage.

Further details of the invention will appear from the following explanations and from the embodiments shown in the drawing.

In the embodiment according to FIGS. 2*a* and 2*b*, the semiconductor body **1** consists of two partial regions **11** and **12** of which **11** is p-conducting and **12** n-conducting. The semiconductor body has moreover layers **2** and **3** for non-blocking contacting of the partial regions **11**, **12**, the over-doping of these layers being respectively indicated by *pp* and *nn*. These layers, serving for current electrodes or connections, are made as thin as possible so that they are well permeable for the entering and leaving radiation. The current connection is effected, for example, by means of annular metal electrodes **4** and **5** (see also end view FIG. 2*b*) to which is connected a voltage source **6**. The polarization of the voltage source is such that the semiconductor **1** is operated in flow direction.

Accordingly, electrons will continuously flow from the partial region into the intermediate layer **1′** of the semiconductor **1** between the two p- and n-regions **11** and **12**, such electrons dropping in the intermediate layer **1′** from their condition of higher energy which they have in the region **12**, to a lower energy level, and particularly recombining with the defect electrons coming from the partial region **11**. In order to obtain a particularly favorable radiation yield, the semiconductor is made disk-shaped with surfaces as plane as possible and above all, with the transition layer as plane as possible. The incident radiation, indicated in FIG. 2*a* by arrows S_1, due to the fact that its frequency ν, is smaller than the quotient from the energy spacing between the valency band and line band and Plank's effect quantum h, permeates into the intermediate layer **1′** between the partial regions **11**, **12** and releases there the amplified radiation which in turn radiates from the semiconductor.

In order to avoid the wavelength of the amplified radiation leaving the semiconductor or the wavelength of the stimulating radiation S_1, respectively, becoming too small, that is, to obtain, for example, a radiation in the millimeter range, there are provided traps, as mentioned before, at least in the intermediate region **1′**, for the electrons coming from the region **12** and for the defect electrons, respectively, coming from the region **11**, the energy spacing of which is small in accordance with the desired wavelength. The electrons passing in these traps from the line band are by the incident radiations S_1 stimulated to pass respectively in the valency band or into a trap of lower energy content lying at the same place, recombining there with the defect electrons and transmitting incident to the corresponding transition the amplified radiation having the desired wavelength corresponding to the small energy spacing.

The energy of the transmitted radiation depends also upon the amount of electrons simultaneously stimulated for transition and therefore is proportional to the strength of the current flowing through the semiconductor **1**. This is utilized in the arrangement according to FIGS. 2*a*, 2*b*, a transformer being for this purpose provided the primary winding **71** of which is, for example, supplied with alternating current from a source **8** by way of a microphone **9**, producing in the secondary winding **72** an alternating voltage superposed upon the voltage from the source **6**. This alternating voltage results in a correspondingly fluctuating current flow through the semiconductor **1**, thus producing a transmitted radiation with energy fluctuating in the rhythm of the speech frequency.

Further details of the invention will appear from the following description with reference to the embodiments illustrated in FIGS. 3 and 4.

In FIG. 3, the disk-shaped semiconductor **1** is arranged between two wave guides **31**, **32** which serve as current connections for the over-doped *pp* and *nn* layers of the semiconductor **1**. The wave guide **31** is connected with the positive (+) pole of the battery **6** the negative (−) pole of which is connected with the wave guide **32** by way of the secondary winding of transformer **7**. The semiconductor is accordingly on a voltage source polarized in flow direction so that the electrons are continuously supplied from the n-conductive part of the semiconductor into the intermediate layer **1′** disposed between the p-zone and the n-zone. The primary winding of the transformer **7**, as already noted in connection with FIG. 2*a*, is connected to battery **8** in series with microphone **9**, so that an alternating voltage in rhythm of the speech frequency impressed on the microphone, is superposed on the direct current voltage from the source **6**.

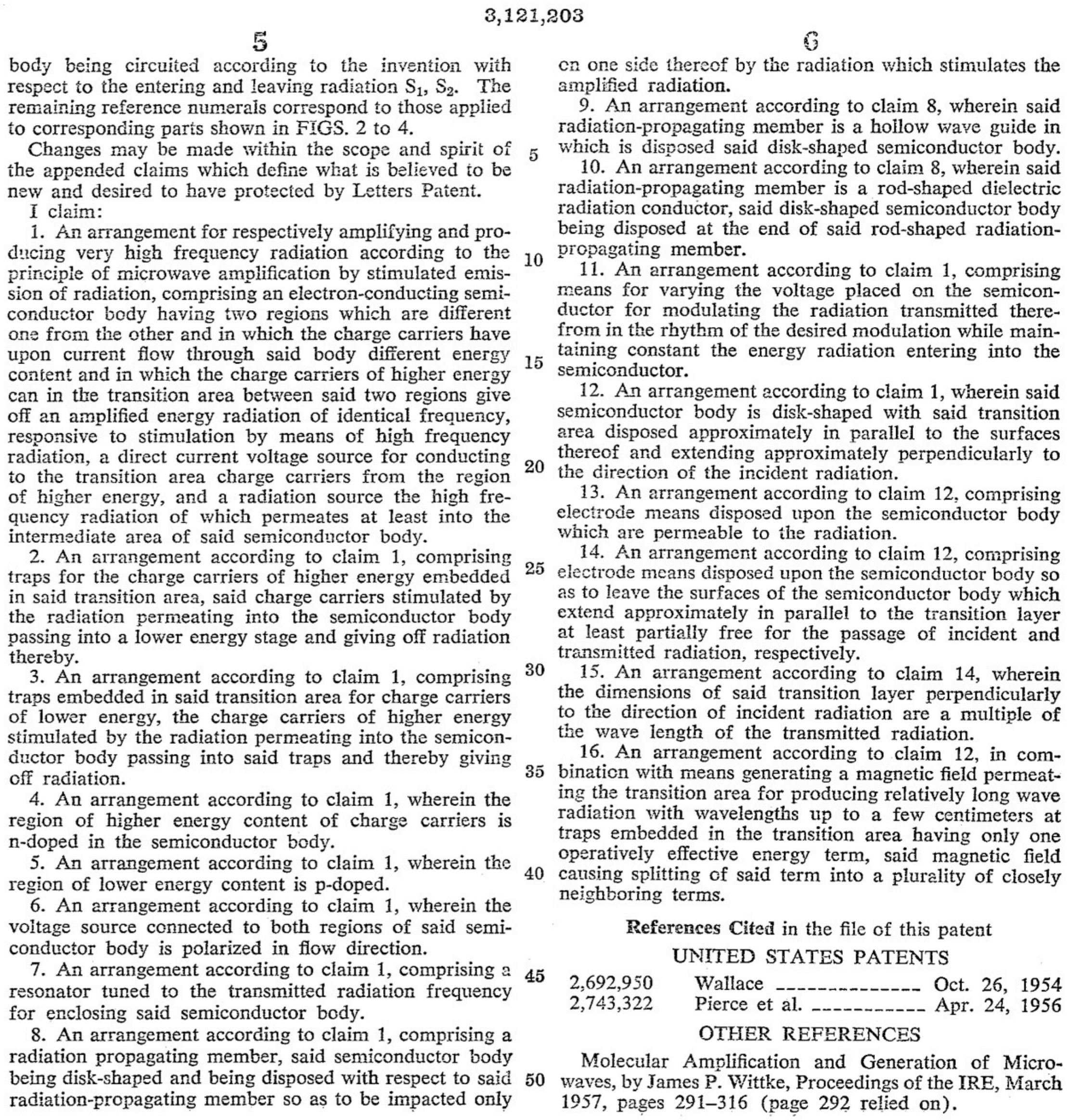
The semiconductor is arranged between the wave guides so that the transition layer **1′** between the two p-n-zones extends approximately perpendicular to the axes of the two wave guides **31**, **32**. The incident radiation indicated at S_1 therefore impacts the intermediate layer **1′** approximately perpendicularly. The amplified radiation S_2 is in the described manner stimulated in this intermediate layer by the stimulation radiation S_1, the amplified radiation S_2 leaving the semiconductor substantially in the direction corresponding to the direction of the incident radiation S_1 and entering the wave guide **32**.

As shown in FIG. 4, dielectric hollow radiators may be used in place of the metallic wave guides **31**, **32**, the incident radiation S_1 being in such case in known manner guided within a rod-shaped non-conductor. The incident radiation S_1 will again impact the transition layer **1′** between the two p-n-zones of the semiconductor approximately perpendicularly. A dielectric radiation conductor may also serve for the transmitted radiation S_2, the radiation leaving the semiconductor entering in such case into the end of a rod-shaped radiator and being in known manner propagated therealong. Contact rings **4** and **5** are provided in FIG. 4 in a similar manner as in FIG. 2*a*, for contacting the hollow conductors to which may be connected in suitable manner (not shown) a voltage source polarized in the flow direction of the p-n-transition, for example, the circuit shown in FIG. 2*a*.

In this embodiment, there is also provided a coil **40** for producing responsive to current flowing therethrough (effected by suitable means) a magnetic field permeating the transition region **1′**, such field being effective to compel in a trap disposed in the transition region, which has only one effective energy term, a splitting of this term into two closely neighboring terms and thereby producing an energy surge depending upon the strength of the magnetic field, which results in a relatively large wavelength of the transmitted radiation.

FIG. 5 shows a semiconductor body **1** disposed within a tuned hollow space resonator **41**, such semiconductor

Figure B.235: Walter Heywang filed detailed patent applications on laser diodes in 1958.



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body being circuited according to the invention with respect to the entering and leaving radiation S_1, S_2. The remaining reference numerals correspond to those applied to corresponding parts shown in FIGS. 2 to 4.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

I claim:

1. An arrangement for respectively amplifying and producing very high frequency radiation according to the principle of microwave amplification by stimulated emission of radiation, comprising an electron-conducting semiconductor body having two regions which are different one from the other and in which the charge carriers have upon current flow through said body different energy content and in which the charge carriers of higher energy can in the transition area between said two regions give off an amplified energy radiation of identical frequency, responsive to stimulation by means of high frequency radiation, a direct current voltage source for conducting to the transition area charge carriers from the region of higher energy, and a radiation source the high frequency radiation of which permeates at least into the intermediate area of said semiconductor body.

2. An arrangement according to claim 1, comprising traps for the charge carriers of higher energy embedded in said transition area, said charge carriers stimulated by the radiation permeating into the semiconductor body passing into a lower energy stage and giving off radiation thereby.

3. An arrangement according to claim 1, comprising traps embedded in said transition area for charge carriers of lower energy, the charge carriers of higher energy stimulated by the radiation permeating into the semiconductor body passing into said traps and thereby giving off radiation.

4. An arrangement according to claim 1, wherein the region of higher energy content of charge carriers is n-doped in the semiconductor body.

5. An arrangement according to claim 1, wherein the region of lower energy content is p-doped.

6. An arrangement according to claim 1, wherein the voltage source connected to both regions of said semiconductor body is polarized in flow direction.

7. An arrangement according to claim 1, comprising a resonator tuned to the transmitted radiation frequency for enclosing said semiconductor body.

8. An arrangement according to claim 1, comprising a radiation propagating member, said semiconductor body being disk-shaped and being disposed with respect to said radiation-propagating member so as to be impacted only

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on one side thereof by the radiation which stimulates the amplified radiation.

9. An arrangement according to claim 8, wherein said radiation-propagating member is a hollow wave guide in which is disposed said disk-shaped semiconductor body.

10. An arrangement according to claim 8, wherein said radiation-propagating member is a rod-shaped dielectric radiation conductor, said disk-shaped semiconductor body being disposed at the end of said rod-shaped radiation-propagating member.

11. An arrangement according to claim 1, comprising means for varying the voltage placed on the semiconductor for modulating the radiation transmitted therefrom in the rhythm of the desired modulation while maintaining constant the energy radiation entering into the semiconductor.

12. An arrangement according to claim 1, wherein said semiconductor body is disk-shaped with said transition area disposed approximately in parallel to the surfaces thereof and extending approximately perpendicularly to the direction of the incident radiation.

13. An arrangement according to claim 12, comprising electrode means disposed upon the semiconductor body which are permeable to the radiation.

14. An arrangement according to claim 12, comprising electrode means disposed upon the semiconductor body so as to leave the surfaces of the semiconductor body which extend approximately in parallel to the transition layer at least partially free for the passage of incident and transmitted radiation, respectively.

15. An arrangement according to claim 14, wherein the dimensions of said transition layer perpendicularly to the direction of incident radiation are a multiple of the wave length of the transmitted radiation.

16. An arrangement according to claim 12, in combination with means generating a magnetic field permeating the transition area for producing relatively long wave radiation with wavelengths up to a few centimeters at traps embedded in the transition area having only one operatively effective energy term, said magnetic field causing splitting of said term into a plurality of closely neighboring terms.

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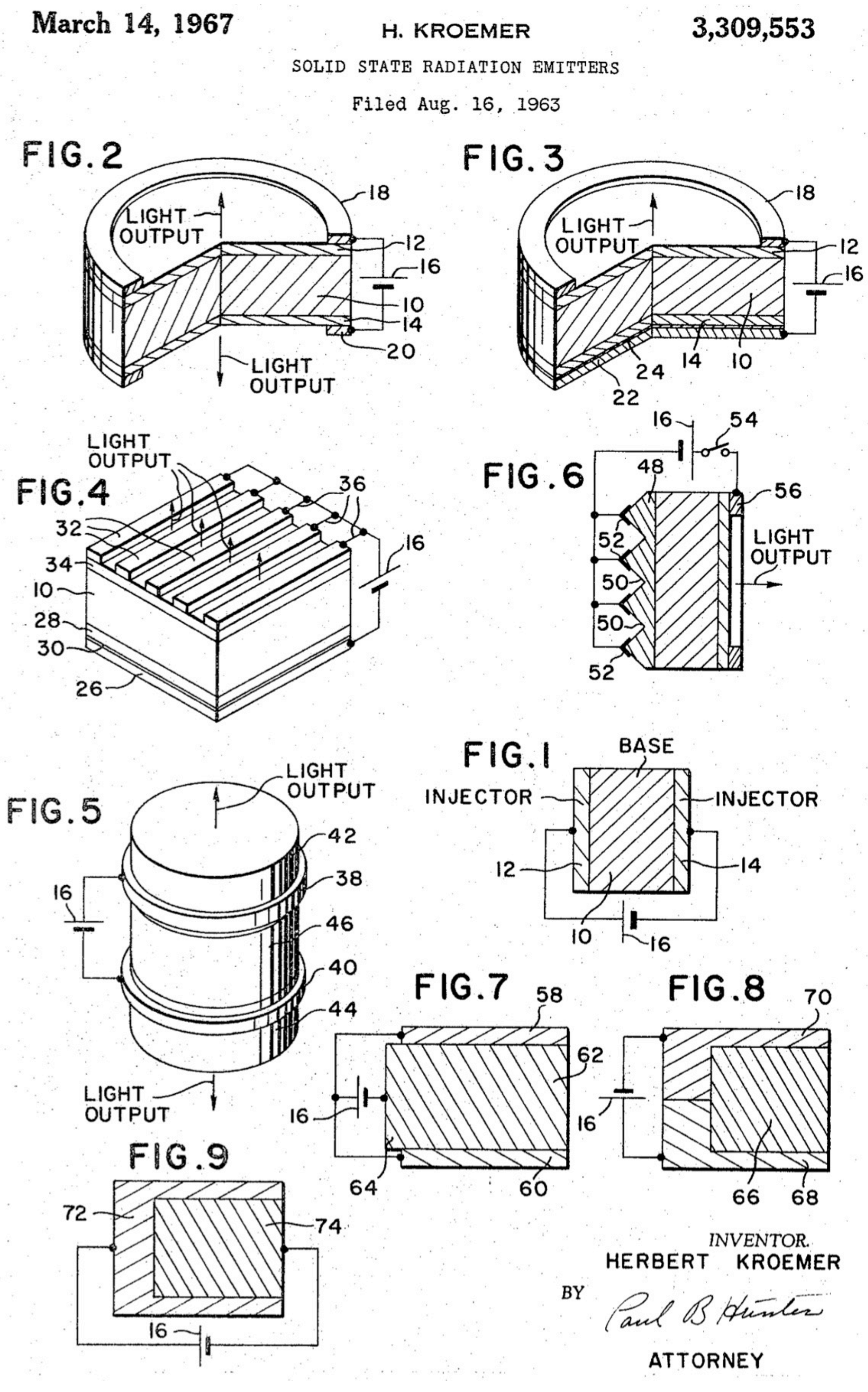
Figure B.236: Walter Heywang filed detailed patent applications on laser diodes in 1958.



March 14, 1967 H. KROEMER 3,309,553

SOLID STATE RADIATION EMITTERS

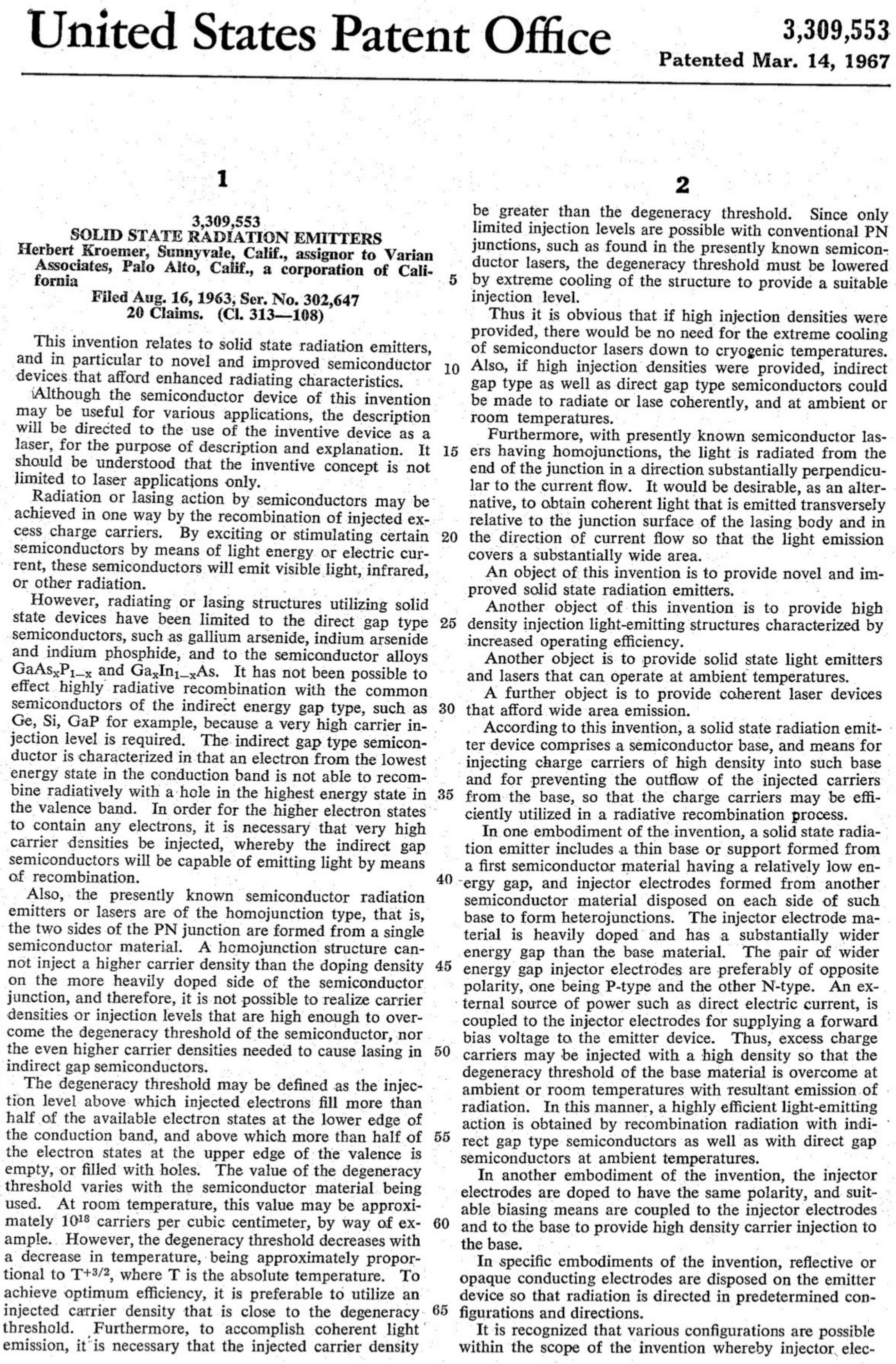
Filed Aug. 16, 1963

INVENTOR.
HERBERT KROEMER

BY Paul B Hunter

ATTORNEY

Figure B.237: Herbert Kroemer invented the double-heterostructure laser diode in 1963.



United States Patent Office

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SOLID STATE RADIATION EMITTERS
Herbert Kroemer, Sunnyvale, Calif., assignor to Varian Associates, Palo Alto, Calif., a corporation of California
Filed Aug. 16, 1963, Ser. No. 302,647
20 Claims. (Cl. 313—108)

This invention relates to solid state radiation emitters, and in particular to novel and improved semiconductor devices that afford enhanced radiating characteristics.

Although the semiconductor device of this invention may be useful for various applications, the description will be directed to the use of the inventive device as a laser, for the purpose of description and explanation. It should be understood that the inventive concept is not limited to laser applications only.

Radiation or lasing action by semiconductors may be achieved in one way by the recombination of injected excess charge carriers. By exciting or stimulating certain semiconductors by means of light energy or electric current, these semiconductors will emit visible light, infrared, or other radiation.

However, radiating or lasing structures utilizing solid state devices have been limited to the direct gap type semiconductors, such as gallium arsenide, indium arsenide and indium phosphide, and to the semiconductor alloys $GaAs_xP_{1-x}$ and $Ga_xIn_{1-x}As$. It has not been possible to effect highly radiative recombination with the common semiconductors of the indirect energy gap type, such as Ge, Si, GaP for example, because a very high carrier injection level is required. The indirect gap type semiconductor is characterized in that an electron from the lowest energy state in the conduction band is not able to recombine radiatively with a hole in the highest energy state in the valence band. In order for the higher electron states to contain any electrons, it is necessary that very high carrier densities be injected, whereby the indirect gap semiconductors will be capable of emitting light by means of recombination.

Also, the presently known semiconductor radiation emitters or lasers are of the homojunction type, that is, the two sides of the PN junction are formed from a single semiconductor material. A homojunction structure cannot inject a higher carrier density than the doping density on the more heavily doped side of the semiconductor junction, and therefore, it is not possible to realize carrier densities or injection levels that are high enough to overcome the degeneracy threshold of the semiconductor, nor the even higher carrier densities needed to cause lasing in indirect gap semiconductors.

The degeneracy threshold may be defined as the injection level above which injected electrons fill more than half of the available electron states at the lower edge of the conduction band, and above which more than half of the electron states at the upper edge of the valence is empty, or filled with holes. The value of the degeneracy threshold varies with the semiconductor material being used. At room temperature, this value may be approximately 10^{18} carriers per cubic centimeter, by way of example. However, the degeneracy threshold decreases with a decrease in temperature, being approximately proportional to $T^{+3/2}$, where T is the absolute temperature. To achieve optimum efficiency, it is preferable to utilize an injected carrier density that is close to the degeneracy threshold. Furthermore, to accomplish coherent light emission, it is necessary that the injected carrier density

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be greater than the degeneracy threshold. Since only limited injection levels are possible with conventional PN junctions, such as found in the presently known semiconductor lasers, the degeneracy threshold must be lowered by extreme cooling of the structure to provide a suitable injection level.

Thus it is obvious that if high injection densities were provided, there would be no need for the extreme cooling of semiconductor lasers down to cryogenic temperatures. Also, if high injection densities were provided, indirect gap type as well as direct gap type semiconductors could be made to radiate or lase coherently, and at ambient or room temperatures.

Furthermore, with presently known semiconductor lasers having homojunctions, the light is radiated from the end of the junction in a direction substantially perpendicular to the current flow. It would be desirable, as an alternative, to obtain coherent light that is emitted transversely relative to the junction surface of the lasing body and in the direction of current flow so that the light emission covers a substantially wide area.

An object of this invention is to provide novel and improved solid state radiation emitters.

Another object of this invention is to provide high density injection light-emitting structures characterized by increased operating efficiency.

Another object is to provide solid state light emitters and lasers that can operate at ambient temperatures.

A further object is to provide coherent laser devices that afford wide area emission.

According to this invention, a solid state radiation emitter device comprises a semiconductor base, and means for injecting charge carriers of high density into such base and for preventing the outflow of the injected carriers from the base, so that the charge carriers may be efficiently utilized in a radiative recombination process.

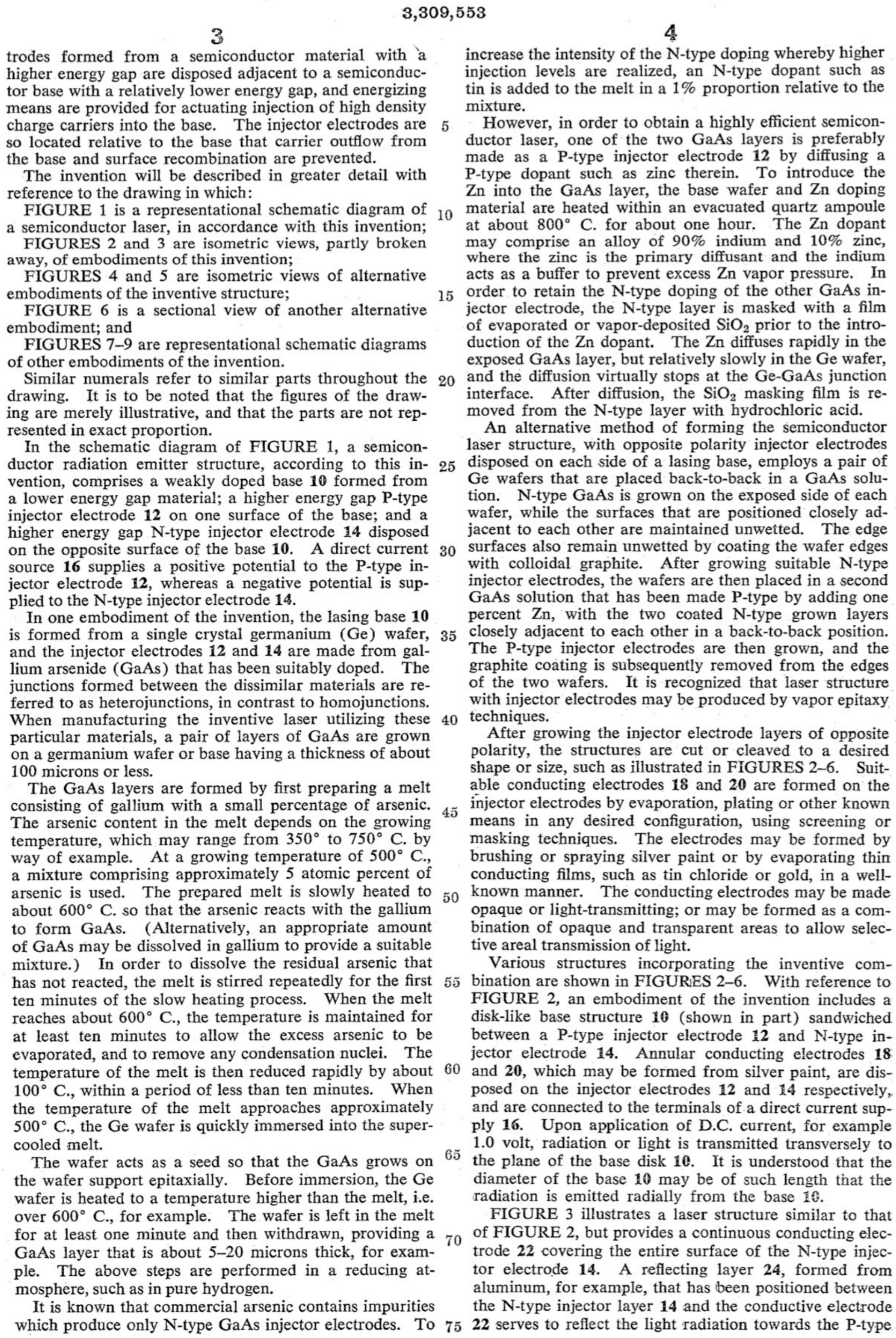
In one embodiment of the invention, a solid state radiation emitter includes a thin base or support formed from a first semiconductor material having a relatively low energy gap, and injector electrodes formed from another semiconductor material disposed on each side of such base to form heterojunctions. The injector electrode material is heavily doped and has a substantially wider energy gap than the base material. The pair of wider energy gap injector electrodes are preferably of opposite polarity, one being P-type and the other N-type. An external source of power such as direct electric current, is coupled to the injector electrodes for supplying a forward bias voltage to the emitter device. Thus, excess charge carriers may be injected with a high density so that the degeneracy threshold of the base material is overcome at ambient or room temperatures with resultant emission of radiation. In this manner, a highly efficient light-emitting action is obtained by recombination radiation with indirect gap type semiconductors as well as with direct gap semiconductors at ambient temperatures.

In another embodiment of the invention, the injector electrodes are doped to have the same polarity, and suitable biasing means are coupled to the injector electrodes and to the base to provide high density carrier injection to the base.

In specific embodiments of the invention, reflective or opaque conducting electrodes are disposed on the emitter device so that radiation is directed in predetermined configurations and directions.

It is recognized that various configurations are possible within the scope of the invention whereby injector elec-

Figure B.238: Herbert Kroemer invented the double-heterostructure laser diode in 1963.



trodes formed from a semiconductor material with a higher energy gap are disposed adjacent to a semiconductor base with a relatively lower energy gap, and energizing means are provided for actuating injection of high density charge carriers into the base. The injector electrodes are so located relative to the base that carrier outflow from the base and surface recombination are prevented.

The invention will be described in greater detail with reference to the drawing in which:

FIGURE 1 is a representational schematic diagram of a semiconductor laser, in accordance with this invention;

FIGURES 2 and 3 are isometric views, partly broken away, of embodiments of this invention;

FIGURES 4 and 5 are isometric views of alternative embodiments of the inventive structure;

FIGURE 6 is a sectional view of another alternative embodiment; and

FIGURES 7–9 are representational schematic diagrams of other embodiments of the invention.

Similar numerals refer to similar parts throughout the drawing. It is to be noted that the figures of the drawing are merely illustrative, and that the parts are not represented in exact proportion.

In the schematic diagram of FIGURE 1, a semiconductor radiation emitter structure, according to this invention, comprises a weakly doped base **10** formed from a lower energy gap material; a higher energy gap P-type injector electrode **12** on one surface of the base; and a higher energy gap N-type injector electrode **14** disposed on the opposite surface of the base **10**. A direct current source **16** supplies a positive potential to the P-type injector electrode **12**, whereas a negative potential is supplied to the N-type injector electrode **14**.

In one embodiment of the invention, the lasing base **10** is formed from a single crystal germanium (Ge) wafer, and the injector electrodes **12** and **14** are made from gallium arsenide (GaAs) that has been suitably doped. The junctions formed between the dissimilar materials are referred to as heterojunctions, in contrast to homojunctions. When manufacturing the inventive laser utilizing these particular materials, a pair of layers of GaAs are grown on a germanium wafer or base having a thickness of about 100 microns or less.

The GaAs layers are formed by first preparing a melt consisting of gallium with a small percentage of arsenic. The arsenic content in the melt depends on the growing temperature, which may range from 350° to 750° C. by way of example. At a growing temperature of 500° C., a mixture comprising approximately 5 atomic percent of arsenic is used. The prepared melt is slowly heated to about 600° C. so that the arsenic reacts with the gallium to form GaAs. (Alternatively, an appropriate amount of GaAs may be dissolved in gallium to provide a suitable mixture.) In order to dissolve the residual arsenic that has not reacted, the melt is stirred repeatedly for the first ten minutes of the slow heating process. When the melt reaches about 600° C., the temperature is maintained for at least ten minutes to allow the excess arsenic to be evaporated, and to remove any condensation nuclei. The temperature of the melt is then reduced rapidly by about 100° C., within a period of less than ten minutes. When the temperature of the melt approaches approximately 500° C., the Ge wafer is quickly immersed into the supercooled melt.

The wafer acts as a seed so that the GaAs grows on the wafer support epitaxially. Before immersion, the Ge wafer is heated to a temperature higher than the melt, i.e. over 600° C., for example. The wafer is left in the melt for at least one minute and then withdrawn, providing a GaAs layer that is about 5–20 microns thick, for example. The above steps are performed in a reducing atmosphere, such as in pure hydrogen.

It is known that commercial arsenic contains impurities which produce only N-type GaAs injector electrodes. To increase the intensity of the N-type doping whereby higher injection levels are realized, an N-type dopant such as tin is added to the melt in a 1% proportion relative to the mixture.

However, in order to obtain a highly efficient semiconductor laser, one of the two GaAs layers is preferably made as a P-type injector electrode **12** by diffusing a P-type dopant such as zinc therein. To introduce the Zn into the GaAs layer, the base wafer and Zn doping material are heated within an evacuated quartz ampoule at about 800° C. for about one hour. The Zn dopant may comprise an alloy of 90% indium and 10% zinc, where the zinc is the primary diffusant and the indium acts as a buffer to prevent excess Zn vapor pressure. In order to retain the N-type doping of the other GaAs injector electrode, the N-type layer is masked with a film of evaporated or vapor-deposited SiO_2 prior to the introduction of the Zn dopant. The Zn diffuses rapidly in the exposed GaAs layer, but relatively slowly in the Ge wafer, and the diffusion virtually stops at the Ge-GaAs junction interface. After diffusion, the SiO_2 masking film is removed from the N-type layer with hydrochloric acid.

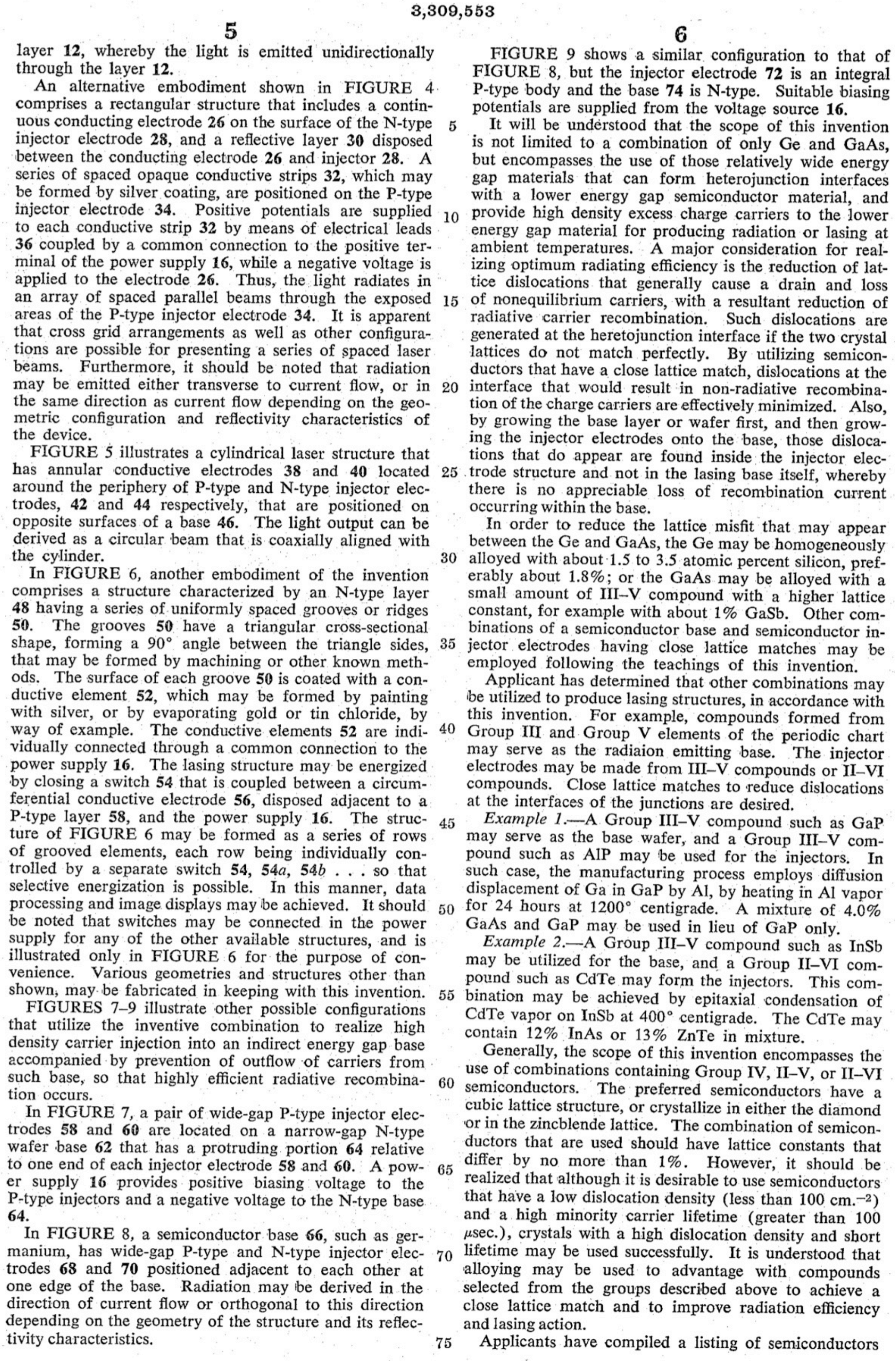
An alternative method of forming the semiconductor laser structure, with opposite polarity injector electrodes disposed on each side of a lasing base, employs a pair of Ge wafers that are placed back-to-back in a GaAs solution. N-type GaAs is grown on the exposed side of each wafer, while the surfaces that are positioned closely adjacent to each other are maintained unwetted. The edge surfaces also remain unwetted by coating the wafer edges with colloidal graphite. After growing suitable N-type injector electrodes, the wafers are then placed in a second GaAs solution that has been made P-type by adding one percent Zn, with the two coated N-type grown layers closely adjacent to each other in a back-to-back position. The P-type injector electrodes are then grown, and the graphite coating is subsequently removed from the edges of the two wafers. It is recognized that laser structure with injector electrodes may be produced by vapor epitaxy techniques.

After growing the injector electrode layers of opposite polarity, the structures are cut or cleaved to a desired shape or size, such as illustrated in FIGURES 2–6. Suitable conducting electrodes **18** and **20** are formed on the injector electrodes by evaporation, plating or other known means in any desired configuration, using screening or masking techniques. The electrodes may be formed by brushing or spraying silver paint or by evaporating thin conducting films, such as tin chloride or gold, in a well-known manner. The conducting electrodes may be made opaque or light-transmitting; or may be formed as a combination of opaque and transparent areas to allow selective areal transmission of light.

Various structures incorporating the inventive combination are shown in FIGURES 2–6. With reference to FIGURE 2, an embodiment of the invention includes a disk-like base structure **10** (shown in part) sandwiched between a P-type injector electrode **12** and N-type injector electrode **14**. Annular conducting electrodes **18** and **20**, which may be formed from silver paint, are disposed on the injector electrodes **12** and **14** respectively, and are connected to the terminals of a direct current supply **16**. Upon application of D.C. current, for example 1.0 volt, radiation or light is transmitted transversely to the plane of the base disk **10**. It is understood that the diameter of the base **10** may be of such length that the radiation is emitted radially from the base **10**.

FIGURE 3 illustrates a laser structure similar to that of FIGURE 2, but provides a continuous conducting electrode **22** covering the entire surface of the N-type injector electrode **14**. A reflecting layer **24**, formed from aluminum, for example, that has been positioned between the N-type injector layer **14** and the conductive electrode **22** serves to reflect the light radiation towards the P-type

Figure B.239: Herbert Kroemer invented the double-heterostructure laser diode in 1963.



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layer **12**, whereby the light is emitted unidirectionally through the layer **12**.

An alternative embodiment shown in FIGURE 4 comprises a rectangular structure that includes a continuous conducting electrode **26** on the surface of the N-type injector electrode **28**, and a reflective layer **30** disposed between the conducting electrode **26** and injector **28**. A series of spaced opaque conductive strips **32**, which may be formed by silver coating, are positioned on the P-type injector electrode **34**. Positive potentials are supplied to each conductive strip **32** by means of electrical leads **36** coupled by a common connection to the positive terminal of the power supply **16**, while a negative voltage is applied to the electrode **26**. Thus, the light radiates in an array of spaced parallel beams through the exposed areas of the P-type injector electrode **34**. It is apparent that cross grid arrangements as well as other configurations are possible for presenting a series of spaced laser beams. Furthermore, it should be noted that radiation may be emitted either transverse to current flow, or in the same direction as current flow depending on the geometric configuration and reflectivity characteristics of the device.

FIGURE 5 illustrates a cylindrical laser structure that has annular conductive electrodes **38** and **40** located around the periphery of P-type and N-type injector electrodes, **42** and **44** respectively, that are positioned on opposite surfaces of a base **46**. The light output can be derived as a circular beam that is coaxially aligned with the cylinder.

In FIGURE 6, another embodiment of the invention comprises a structure characterized by an N-type layer **48** having a series of uniformly spaced grooves or ridges **50**. The grooves **50** have a triangular cross-sectional shape, forming a 90° angle between the triangle sides, that may be formed by machining or other known methods. The surface of each groove **50** is coated with a conductive element **52**, which may be formed by painting with silver, or by evaporating gold or tin chloride, by way of example. The conductive elements **52** are individually connected through a common connection to the power supply **16**. The lasing structure may be energized by closing a switch **54** that is coupled between a circumferential conductive electrode **56**, disposed adjacent to a P-type layer **58**, and the power supply **16**. The structure of FIGURE 6 may be formed as a series of rows of grooved elements, each row being individually controlled by a separate switch **54**, **54*a***, **54*b*** . . . so that selective energization is possible. In this manner, data processing and image displays may be achieved. It should be noted that switches may be connected in the power supply for any of the other available structures, and is illustrated only in FIGURE 6 for the purpose of convenience. Various geometries and structures other than shown, may be fabricated in keeping with this invention.

FIGURES 7–9 illustrate other possible configurations that utilize the inventive combination to realize high density carrier injection into an indirect energy gap base accompanied by prevention of outflow of carriers from such base, so that highly efficient radiative recombination occurs.

In FIGURE 7, a pair of wide-gap P-type injector electrodes **58** and **60** are located on a narrow-gap N-type wafer base **62** that has a protruding portion **64** relative to one end of each injector electrode **58** and **60**. A power supply **16** provides positive biasing voltage to the P-type injectors and a negative voltage to the N-type base **64**.

In FIGURE 8, a semiconductor base **66**, such as germanium, has wide-gap P-type and N-type injector electrodes **68** and **70** positioned adjacent to each other at one edge of the base. Radiation may be derived in the direction of current flow or orthogonal to this direction depending on the geometry of the structure and its reflectivity characteristics.

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FIGURE 9 shows a similar configuration to that of FIGURE 8, but the injector electrode **72** is an integral P-type body and the base **74** is N-type. Suitable biasing potentials are supplied from the voltage source **16**.

It will be understood that the scope of this invention is not limited to a combination of only Ge and GaAs, but encompasses the use of those relatively wide energy gap materials that can form heterojunction interfaces with a lower energy gap semiconductor material, and provide high density excess charge carriers to the lower energy gap material for producing radiation or lasing at ambient temperatures. A major consideration for realizing optimum radiating efficiency is the reduction of lattice dislocations that generally cause a drain and loss of nonequilibrium carriers, with a resultant reduction of radiative carrier recombination. Such dislocations are generated at the heretojunction interface if the two crystal lattices do not match perfectly. By utilizing semiconductors that have a close lattice match, dislocations at the interface that would result in non-radiative recombination of the charge carriers are effectively minimized. Also, by growing the base layer or wafer first, and then growing the injector electrodes onto the base, those dislocations that do appear are found inside the injector electrode structure and not in the lasing base itself, whereby there is no appreciable loss of recombination current occurring within the base.

In order to reduce the lattice misfit that may appear between the Ge and GaAs, the Ge may be homogeneously alloyed with about 1.5 to 3.5 atomic percent silicon, preferably about 1.8%; or the GaAs may be alloyed with a small amount of III–V compound with a higher lattice constant, for example with about 1% GaSb. Other combinations of a semiconductor base and semiconductor injector electrodes having close lattice matches may be employed following the teachings of this invention.

Applicant has determined that other combinations may be utilized to produce lasing structures, in accordance with this invention. For example, compounds formed from Group III and Group V elements of the periodic chart may serve as the radiaion emitting base. The injector electrodes may be made from III–V compounds or II–VI compounds. Close lattice matches to reduce dislocations at the interfaces of the junctions are desired.

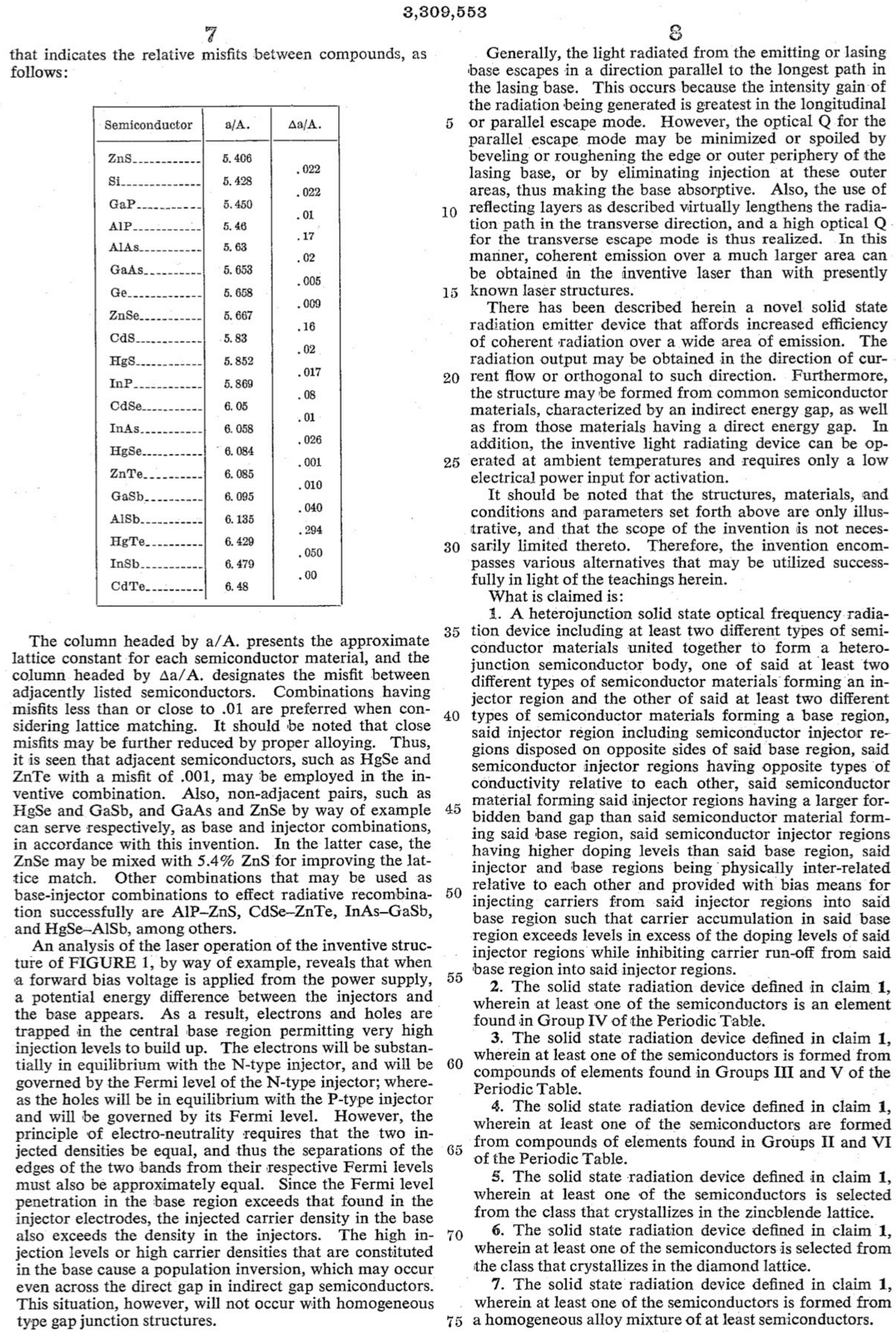
Example 1.—A Group III–V compound such as GaP may serve as the base wafer, and a Group III–V compound such as AlP may be used for the injectors. In such case, the manufacturing process employs diffusion displacement of Ga in GaP by Al, by heating in Al vapor for 24 hours at 1200° centigrade. A mixture of 4.0% GaAs and GaP may be used in lieu of GaP only.

Example 2.—A Group III–V compound such as InSb may be utilized for the base, and a Group II–VI compound such as CdTe may form the injectors. This combination may be achieved by epitaxial condensation of CdTe vapor on InSb at 400° centigrade. The CdTe may contain 12% InAs or 13% ZnTe in mixture.

Generally, the scope of this invention encompasses the use of combinations containing Group IV, II–V, or II–VI semiconductors. The preferred semiconductors have a cubic lattice structure, or crystallize in either the diamond or in the zincblende lattice. The combination of semiconductors that are used should have lattice constants that differ by no more than 1%. However, it should be realized that although it is desirable to use semiconductors that have a low dislocation density (less than 100 $cm.^{-2}$) and a high minority carrier lifetime (greater than 100 μsec.), crystals with a high dislocation density and short lifetime may be used successfully. It is understood that alloying may be used to advantage with compounds selected from the groups described above to achieve a close lattice match and to improve radiation efficiency and lasing action.

Applicants have compiled a listing of semiconductors

Figure B.240: Herbert Kroemer invented the double-heterostructure laser diode in 1963.



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that indicates the relative misfits between compounds, as follows:

Semiconductor	a/A.	Δa/A.
ZnS	5.406	.022
Si	5.428	.022
GaP	5.450	.01
AlP	5.46	.17
AlAs	5.63	.02
GaAs	5.653	.005
Ge	5.658	.009
ZnSe	5.667	.16
CdS	5.83	.02
HgS	5.852	.017
InP	5.869	.08
CdSe	6.05	.01
InAs	6.058	.026
HgSe	6.084	.001
ZnTe	6.085	.010
GaSb	6.095	.040
AlSb	6.135	.294
HgTe	6.429	.050
InSb	6.479	.00
CdTe	6.48	

The column headed by a/A. presents the approximate lattice constant for each semiconductor material, and the column headed by Δa/A. designates the misfit between adjacently listed semiconductors. Combinations having misfits less than or close to .01 are preferred when considering lattice matching. It should be noted that close misfits may be further reduced by proper alloying. Thus, it is seen that adjacent semiconductors, such as HgSe and ZnTe with a misfit of .001, may be employed in the inventive combination. Also, non-adjacent pairs, such as HgSe and GaSb, and GaAs and ZnSe by way of example can serve respectively, as base and injector combinations, in accordance with this invention. In the latter case, the ZnSe may be mixed with 5.4% ZnS for improving the lattice match. Other combinations that may be used as base-injector combinations to effect radiative recombination successfully are AlP–ZnS, CdSe–ZnTe, InAs–GaSb, and HgSe–AlSb, among others.

An analysis of the laser operation of the inventive structure of FIGURE 1, by way of example, reveals that when a forward bias voltage is applied from the power supply, a potential energy difference between the injectors and the base appears. As a result, electrons and holes are trapped in the central base region permitting very high injection levels to build up. The electrons will be substantially in equilibrium with the N-type injector, and will be governed by the Fermi level of the N-type injector; whereas the holes will be in equilibrium with the P-type injector and will be governed by its Fermi level. However, the principle of electro-neutrality requires that the two injected densities be equal, and thus the separations of the edges of the two bands from their respective Fermi levels must also be approximately equal. Since the Fermi level penetration in the base region exceeds that found in the injector electrodes, the injected carrier density in the base also exceeds the density in the injectors. The high injection levels or high carrier densities that are constituted in the base cause a population inversion, which may occur even across the direct gap in indirect gap semiconductors. This situation, however, will not occur with homogeneous type gap junction structures.

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Generally, the light radiated from the emitting or lasing base escapes in a direction parallel to the longest path in the lasing base. This occurs because the intensity gain of the radiation being generated is greatest in the longitudinal or parallel escape mode. However, the optical Q for the parallel escape mode may be minimized or spoiled by beveling or roughening the edge or outer periphery of the lasing base, or by eliminating injection at these outer areas, thus making the base absorptive. Also, the use of reflecting layers as described virtually lengthens the radiation path in the transverse direction, and a high optical Q for the transverse escape mode is thus realized. In this manner, coherent emission over a much larger area can be obtained in the inventive laser than with presently known laser structures.

There has been described herein a novel solid state radiation emitter device that affords increased efficiency of coherent radiation over a wide area of emission. The radiation output may be obtained in the direction of current flow or orthogonal to such direction. Furthermore, the structure may be formed from common semiconductor materials, characterized by an indirect energy gap, as well as from those materials having a direct energy gap. In addition, the inventive light radiating device can be operated at ambient temperatures and requires only a low electrical power input for activation.

It should be noted that the structures, materials, and conditions and parameters set forth above are only illustrative, and that the scope of the invention is not necessarily limited thereto. Therefore, the invention encompasses various alternatives that may be utilized successfully in light of the teachings herein.

What is claimed is:

1. A heterojunction solid state optical frequency radiation device including at least two different types of semiconductor materials united together to form a heterojunction semiconductor body, one of said at least two different types of semiconductor materials forming an injector region and the other of said at least two different types of semiconductor materials forming a base region, said injector region including semiconductor injector regions disposed on opposite sides of said base region, said semiconductor injector regions having opposite types of conductivity relative to each other, said semiconductor material forming said injector regions having a larger forbidden band gap than said semiconductor material forming said base region, said semiconductor injector regions having higher doping levels than said base region, said injector and base regions being physically inter-related relative to each other and provided with bias means for injecting carriers from said injector regions into said base region such that carrier accumulation in said base region exceeds levels in excess of the doping levels of said injector regions while inhibiting carrier run-off from said base region into said injector regions.

2. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors is an element found in Group IV of the Periodic Table.

3. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors is formed from compounds of elements found in Groups III and V of the Periodic Table.

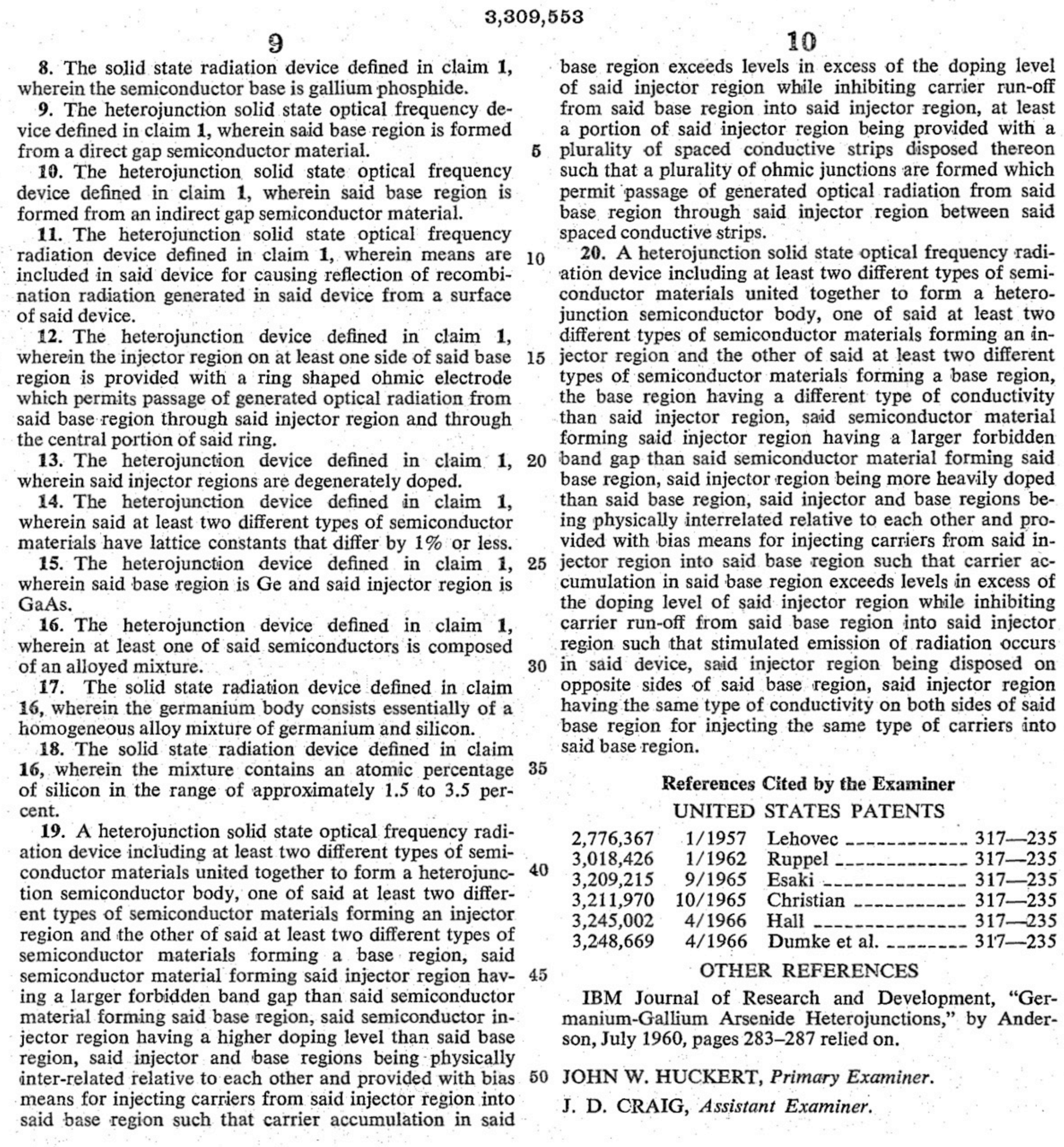
4. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors are formed from compounds of elements found in Groups II and VI of the Periodic Table.

5. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors is selected from the class that crystallizes in the zincblende lattice.

6. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors is selected from the class that crystallizes in the diamond lattice.

7. The solid state radiation device defined in claim **1**, wherein at least one of the semiconductors is formed from a homogeneous alloy mixture of at least semiconductors.

Figure B.241: Herbert Kroemer invented the double-heterostructure laser diode in 1963.



3,309,553

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8. The solid state radiation device defined in claim **1**, wherein the semiconductor base is gallium phosphide.

9. The heterojunction solid state optical frequency device defined in claim **1**, wherein said base region is formed from a direct gap semiconductor material.

10. The heterojunction solid state optical frequency device defined in claim **1**, wherein said base region is formed from an indirect gap semiconductor material.

11. The heterojunction solid state optical frequency radiation device defined in claim **1**, wherein means are included in said device for causing reflection of recombination radiation generated in said device from a surface of said device.

12. The heterojunction device defined in claim **1**, wherein the injector region on at least one side of said base region is provided with a ring shaped ohmic electrode which permits passage of generated optical radiation from said base region through said injector region and through the central portion of said ring.

13. The heterojunction device defined in claim **1**, wherein said injector regions are degenerately doped.

14. The heterojunction device defined in claim **1**, wherein said at least two different types of semiconductor materials have lattice constants that differ by 1% or less.

15. The heterojunction device defined in claim **1**, wherein said base region is Ge and said injector region is GaAs.

16. The heterojunction device defined in claim **1**, wherein at least one of said semiconductors is composed of an alloyed mixture.

17. The solid state radiation device defined in claim **16**, wherein the germanium body consists essentially of a homogeneous alloy mixture of germanium and silicon.

18. The solid state radiation device defined in claim **16**, wherein the mixture contains an atomic percentage of silicon in the range of approximately 1.5 to 3.5 percent.

19. A heterojunction solid state optical frequency radiation device including at least two different types of semiconductor materials united together to form a heterojunction semiconductor body, one of said at least two different types of semiconductor materials forming an injector region and the other of said at least two different types of semiconductor materials forming a base region, said semiconductor material forming said injector region having a larger forbidden band gap than said semiconductor material forming said base region, said semiconductor injector region having a higher doping level than said base region, said injector and base regions being physically inter-related relative to each other and provided with bias means for injecting carriers from said injector region into said base region such that carrier accumulation in said base region exceeds levels in excess of the doping level of said injector region while inhibiting carrier run-off from said base region into said injector region, at least a portion of said injector region being provided with a plurality of spaced conductive strips disposed thereon such that a plurality of ohmic junctions are formed which permit passage of generated optical radiation from said base region through said injector region between said spaced conductive strips.

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20. A heterojunction solid state optical frequency radiation device including at least two different types of semiconductor materials united together to form a heterojunction semiconductor body, one of said at least two different types of semiconductor materials forming an injector region and the other of said at least two different types of semiconductor materials forming a base region, the base region having a different type of conductivity than said injector region, said semiconductor material forming said injector region having a larger forbidden band gap than said semiconductor material forming said base region, said injector region being more heavily doped than said base region, said injector and base regions being physically interrelated relative to each other and provided with bias means for injecting carriers from said injector region into said base region such that carrier accumulation in said base region exceeds levels in excess of the doping level of said injector region while inhibiting carrier run-off from said base region into said injector region such that stimulated emission of radiation occurs in said device, said injector region being disposed on opposite sides of said base region, said injector region having the same type of conductivity on both sides of said base region for injecting the same type of carriers into said base region.

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IBM Journal of Research and Development, "Germanium-Gallium Arsenide Heterojunctions," by Anderson, July 1960, pages 283–287 relied on.

JOHN W. HUCKERT, *Primary Examiner*.

J. D. CRAIG, *Assistant Examiner*.

Figure B.242: Herbert Kroemer invented the double-heterostructure laser diode in 1963.

B.5 Postwar Transfer of Microelectronics Technologies

[Detailed technical information on semiconductors and microelectronics technologies was transferred from the German-speaking world to Allied countries after World War II. Some examples have already been mentioned earlier in this appendix. Pages 2926–3013 present additional examples of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge. There was likely a great deal of additional technology transfer that was not recorded in official documents.

The financially and politically powerful combined corporate entity American Telephone & Telegraph (AT&T), Bell Telephone Laboratories (Bell Labs), and Western Electric (the manufacturing arm of the corporation) committed a number of its personnel to studying technology from the German-speaking world, both collecting information in Europe and analyzing information that had been sent from Europe to the United States. While certainly not an exhaustive list, some representative examples of involved personnel include:

- Edwin Y. Webb Jr. worked for AT&T 1928–1944 before entering government service during the war. He was Chief in charge of investigating and transferring electronics and communications-related technologies out of the German-speaking world for the United States.

- George Richert worked for Bell Telephone 1927–1942 before entering government service during the war. He was Assistant Chief in charge of investigating and transferring electronics and communications-related technologies out of the German-speaking world for the United States.

- T. M. Odarenko worked for Bell Telephone 1928–1943 before entering government service during the war. He was one of the senior U.S. scientists involved in investigating and transferring electronics and other technologies out of Germany and Austria.

- Pierre Mertz worked at Bell Labs and visited Germany to transfer electronics and related technologies.

- Frederick E. Henderson worked at Western Electric and visited Germany to transfer electronics and related technologies.

- Roland H. McCarthy worked at Western Electric and visited Germany to transfer electronics and related technologies.

- John A. Parrott worked at AT&T and visited Germany to transfer electronics and related technologies.

- R. E. Russell worked at AT&T and visited Germany to transfer electronics and related technologies.

- John R. Townsend worked at Bell Labs and studied German hardware and information both in Europe and at Bell.

- Victor Ronci worked at Bell Labs developing improved versions of vacuum tubes, and was involved in analyzing captured German hardware and information that was sent to Bell Labs.

- Lloyd Espenschied worked at Bell Labs to study captured German hardware and information that was sent to the lab.
- John N. Shive worked at Bell Labs to study captured German hardware and information that was sent to the lab.
- F. A. Cowan worked at AT&T and advised the U.S. government what specific targets and topics to investigate with regard to wire communications systems.
- George W. Gilman worked at Bell Labs and advised the U.S. government what specific targets and topics to investigate with regard to radio communications systems.
- R. E. Poole worked at Bell Labs and advised the U.S. government what specific targets and topics to investigate with regard to radar systems.
- W. H. Martin worked at Bell Labs and advised the U.S. government what specific targets and topics to investigate with regard to "special systems."
- Julian Blanchard was assigned by AT&T/Bell/Western Electric to work full time in Washington, D.C. during 1946–1947 searching the many tons of captured German reports for any useful information he could send to the corporation.
- Both William Shockley and John Bardeen of Bell Labs visited laboratories in several European countries during a research trip from June through August 1947. During that time, Shockley or Bardeen may have encountered scientists, reports, or information from the earlier transistor work that had been conducted in the German-speaking world. Alternatively they might have encountered Allied investigators who had already examined that work and could pass along useful information. Shockley and Bardeen's transistor experiments at Bell Labs were entirely unsuccessful during the long period before their European trip, and extremely successful very shortly after their trip [Hoddeson and Daitch 2002, pp. 128–131].

Other American and British electronics and other companies also committed large numbers of investigators to study and bring back technologies from the German-speaking world.

Many English-language reports were written about German microelectronics technologies. Some examples include:

> BIOS 724. *Electronic Principles as Applied in Germany to the Testing of Materials.* [Piezo-electric, electronic materials testing]
>
> BIOS 725. *German Research on Rectifiers and Semi-Conductors.*
>
> BIOS 980. *Electro-Acoustics in Germany. Part I & II.*
>
> BIOS 1751. *German Research on Semi-Conductors, Metal Rectifiers, Detectors and Photocells.*
>
> FIAT 54. *German Developments in Semi-Conducting Materials.* [by T. M. Odarenko]
>
> FIAT 56. *Selenium Rectifier Development in Germany.* [by T. M. Odarenko]

FIAT 272. *Telefunken A.G. Dachau, Germany and C. H. F. Mueller A.G. Fuhlsbuettel, Hamburg.* [Silicon crystals]

FIAT 294. *Interrogation of German Television and Electronic Authorities.* [Electronics developments, photoelectric, IR image tubes, silicon detector cells]

FIAT 641. *The Interrogation of German Scientists Regarding Quartz Crystals and other Piezoelectric Materials.*

FIAT 706. *Report on Selenium Dry Rectifier Developments.*

FIAT 954. *A Highly Sensitive D.C. Controlling & Measuring Device.* [Amplifier]

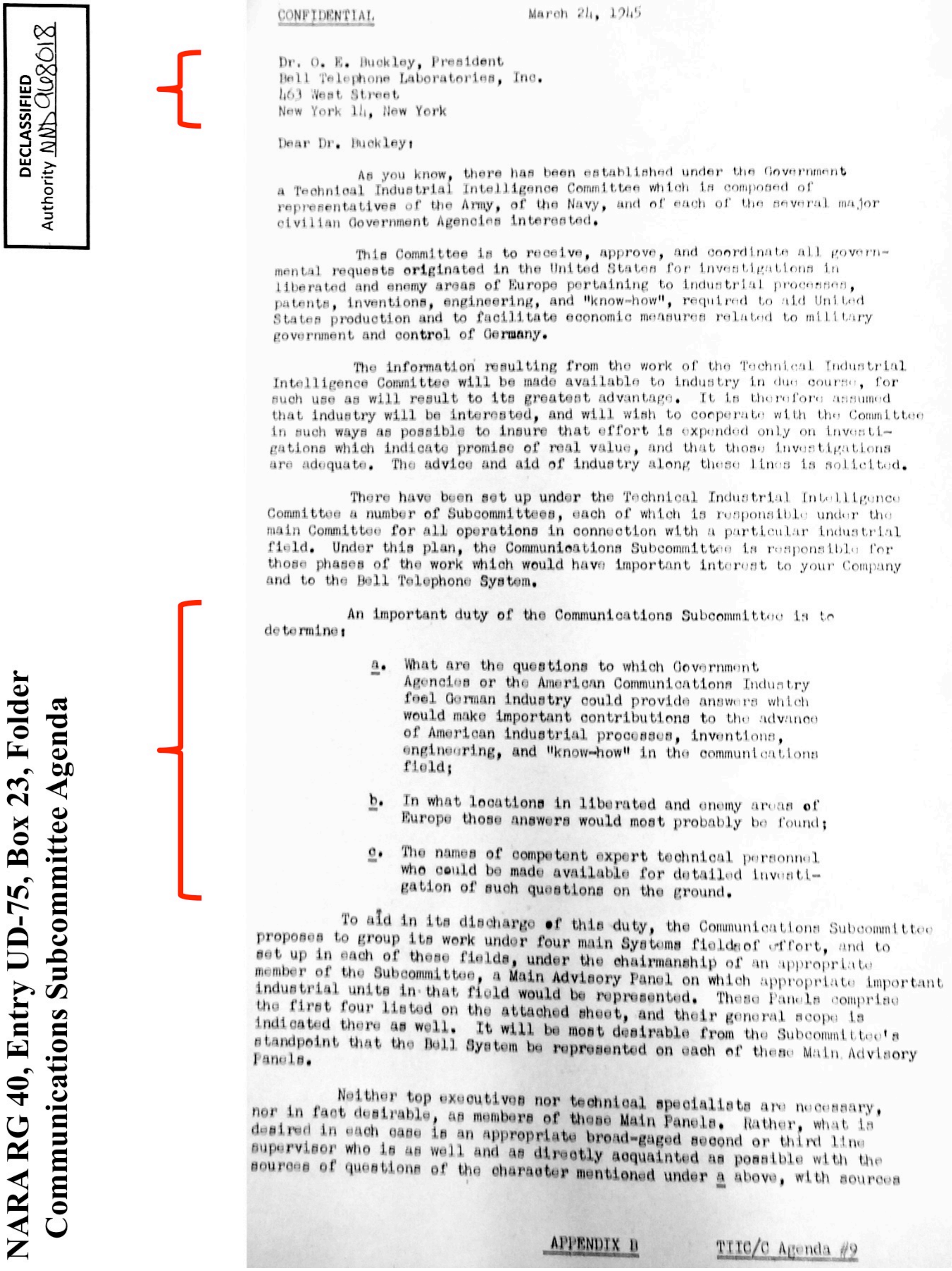
For example, BIOS 725 described how German groups were making wafers of monocrystalline pure silicon, doping semiconductor materials with impurities to create the desired electrical properties, and producing semiconductor devices both from silicon and from germanium:

> Impurities in a semi-conductor produce additional energy-levels; perhaps a pure material could not be a semi-conductor. There must be some broadening of the energy levels into bands... Joos tried to produce large crystals of silicon for use in silicon-carbon detectors for cm. waves. The method was deposition from a solution of silicon in molten aluminum. The crystals so obtained were spectroscopically pure... They were aggregations of thin plates... Prof. Pohl confirmed that Dr. König had studied germanium and silicon rectifiers at Göttingen...

Countless tons of both electronics equipment and German technical documents were shipped to the United States and other countries.

German-speaking scientists were repeatedly interrogated in Europe, and/or brought to the United States or other countries to work, as covered in Chapter 11. For example, Hans K. Ziegler (German, 1911–1999) came to the United States in Operation Paperclip. He became the Chief Scientist of a U.S. Army laboratory in Fort Monmouth, New Jersey, that employed many other German-speaking scientists and harnessed many microelectronics technologies acquired from Germany, Austria, and Czech territory [Fort Monmouth Historical Office 2008]. See pp. 1153–1154, 2760, and 3013. Many other German-speaking scientists were hired by other U.S. laboratories or companies.

On top of all of the technology transfer that was documented to have occurred, it seems likely that there was a considerable amount of additional technology transfer that was not recorded in official documents. The German-speaking world was filled with advanced technologies, and it would have been a great temptation for any Allied investigator or company to try to claim some of those technologies in order to get ahead of their rivals. Thus the innovations from the German-speaking world probably had a much greater postwar impact on the United States and other countries than can be strictly proven from the existing archival documents.]



CONFIDENTIAL March 24, 1945

Dr. O. E. Buckley, President
Bell Telephone Laboratories, Inc.
463 West Street
New York 14, New York

Dear Dr. Buckley:

As you know, there has been established under the Government a Technical Industrial Intelligence Committee which is composed of representatives of the Army, of the Navy, and of each of the several major civilian Government Agencies interested.

This Committee is to receive, approve, and coordinate all governmental requests originated in the United States for investigations in liberated and enemy areas of Europe pertaining to industrial processes, patents, inventions, engineering, and "know-how", required to aid United States production and to facilitate economic measures related to military government and control of Germany.

The information resulting from the work of the Technical Industrial Intelligence Committee will be made available to industry in due course, for such use as will result to its greatest advantage. It is therefore assumed that industry will be interested, and will wish to cooperate with the Committee in such ways as possible to insure that effort is expended only on investigations which indicate promise of real value, and that those investigations are adequate. The advice and aid of industry along these lines is solicited.

There have been set up under the Technical Industrial Intelligence Committee a number of Subcommittees, each of which is responsible under the main Committee for all operations in connection with a particular industrial field. Under this plan, the Communications Subcommittee is responsible for those phases of the work which would have important interest to your Company and to the Bell Telephone System.

An important duty of the Communications Subcommittee is to determine:

a. What are the questions to which Government Agencies or the American Communications Industry feel German industry could provide answers which would make important contributions to the advance of American industrial processes, inventions, engineering, and "know-how" in the communications field;

b. In what locations in liberated and enemy areas of Europe those answers would most probably be found;

c. The names of competent expert technical personnel who could be made available for detailed investigation of such questions on the ground.

To aid in its discharge of this duty, the Communications Subcommittee proposes to group its work under four main Systems fields of effort, and to set up in each of these fields, under the chairmanship of an appropriate member of the Subcommittee, a Main Advisory Panel on which appropriate important industrial units in that field would be represented. These Panels comprise the first four listed on the attached sheet, and their general scope is indicated there as well. It will be most desirable from the Subcommittee's standpoint that the Bell System be represented on each of these Main Advisory Panels.

Neither top executives nor technical specialists are necessary, nor in fact desirable, as members of these Main Panels. Rather, what is desired in each case is an appropriate broad-gaged second or third line supervisor who is as well and as directly acquainted as possible with the sources of questions of the character mentioned under a above, with sources

APPENDIX B TIIC/C Agenda #9

Figure B.243: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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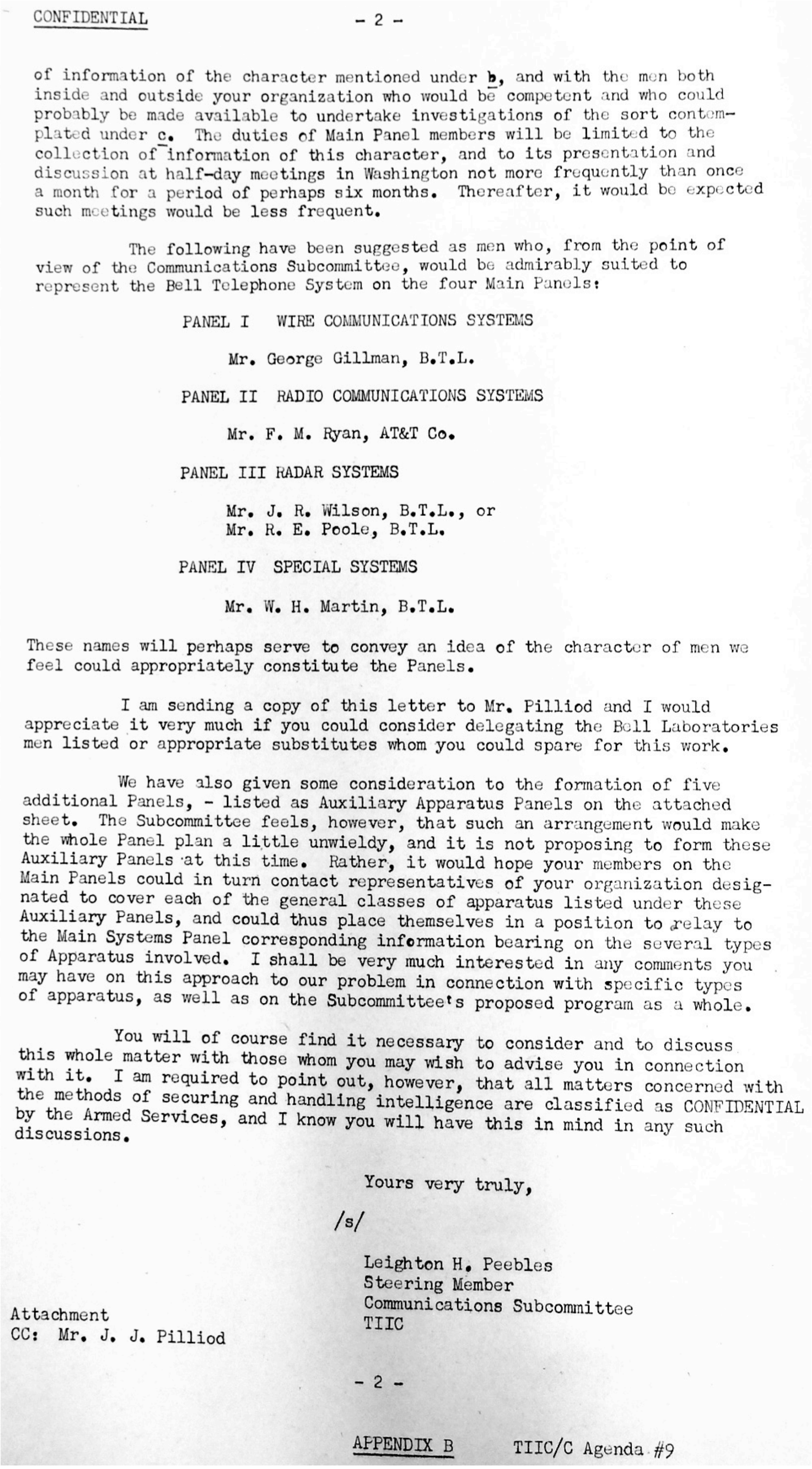

CONFIDENTIAL - 2 -

of information of the character mentioned under b, and with the men both inside and outside your organization who would be competent and who could probably be made available to undertake investigations of the sort contemplated under c. The duties of Main Panel members will be limited to the collection of information of this character, and to its presentation and discussion at half-day meetings in Washington not more frequently than once a month for a period of perhaps six months. Thereafter, it would be expected such meetings would be less frequent.

The following have been suggested as men who, from the point of view of the Communications Subcommittee, would be admirably suited to represent the Bell Telephone System on the four Main Panels:

PANEL I WIRE COMMUNICATIONS SYSTEMS

Mr. George Gillman, B.T.L.

PANEL II RADIO COMMUNICATIONS SYSTEMS

Mr. F. M. Ryan, AT&T Co.

PANEL III RADAR SYSTEMS

Mr. J. R. Wilson, B.T.L., or
Mr. R. E. Poole, B.T.L.

PANEL IV SPECIAL SYSTEMS

Mr. W. H. Martin, B.T.L.

These names will perhaps serve to convey an idea of the character of men we feel could appropriately constitute the Panels.

I am sending a copy of this letter to Mr. Pilliod and I would appreciate it very much if you could consider delegating the Bell Laboratories men listed or appropriate substitutes whom you could spare for this work.

We have also given some consideration to the formation of five additional Panels, - listed as Auxiliary Apparatus Panels on the attached sheet. The Subcommittee feels, however, that such an arrangement would make the whole Panel plan a little unwieldy, and it is not proposing to form these Auxiliary Panels at this time. Rather, it would hope your members on the Main Panels could in turn contact representatives of your organization designated to cover each of the general classes of apparatus listed under these Auxiliary Panels, and could thus place themselves in a position to relay to the Main Systems Panel corresponding information bearing on the several types of Apparatus involved. I shall be very much interested in any comments you may have on this approach to our problem in connection with specific types of apparatus, as well as on the Subcommittee's proposed program as a whole.

You will of course find it necessary to consider and to discuss this whole matter with those whom you may wish to advise you in connection with it. I am required to point out, however, that all matters concerned with the methods of securing and handling intelligence are classified as CONFIDENTIAL by the Armed Services, and I know you will have this in mind in any such discussions.

Yours very truly,

/s/

Leighton H. Peebles
Steering Member
Communications Subcommittee
TIIC

Attachment
CC: Mr. J. J. Pilliod

- 2 -

APPENDIX B TIIC/C Agenda #9

NARA RG 40, Entry UD-75, Box 23, Folder
Communications Subcommittee Agenda

Figure B.244: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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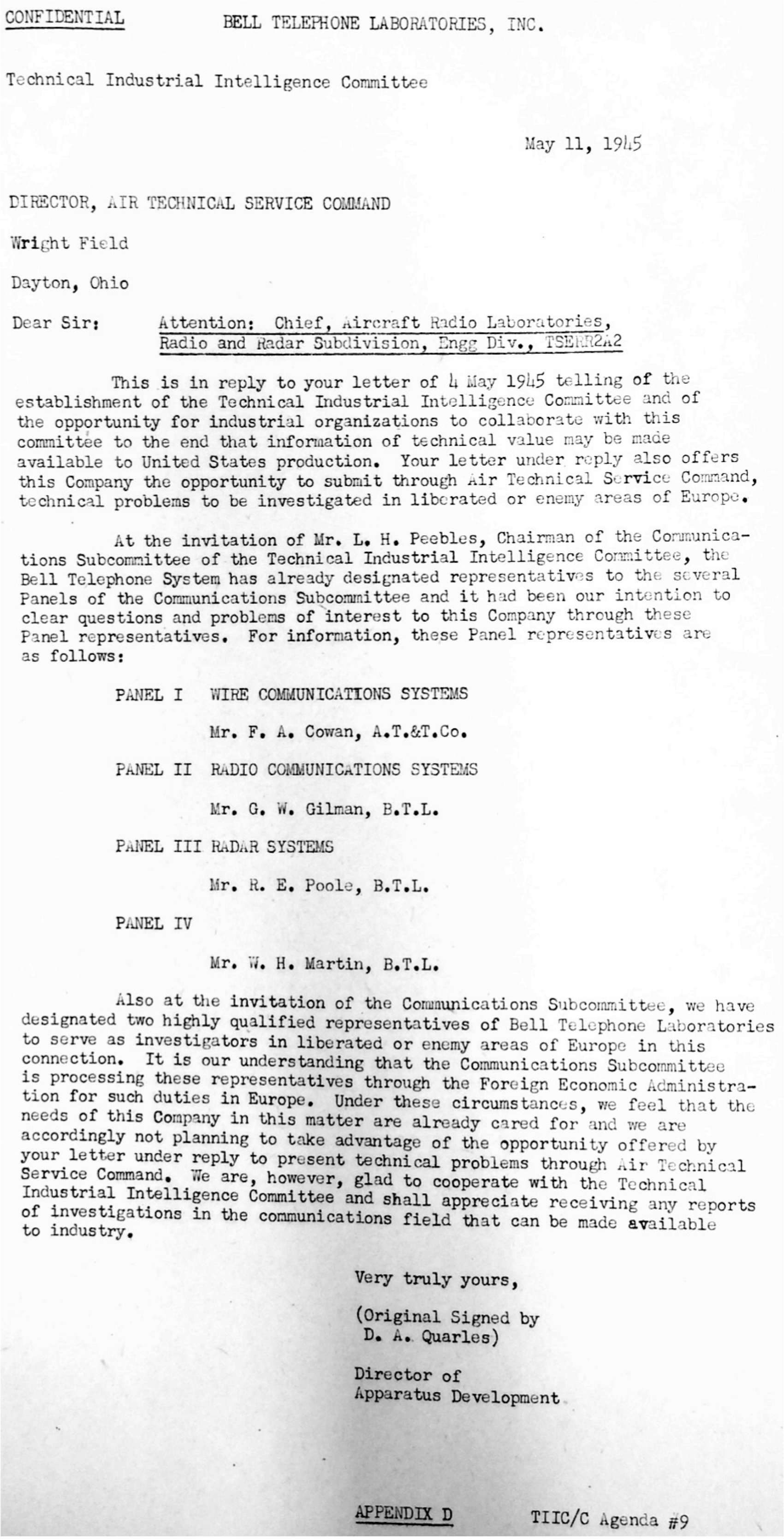


CONFIDENTIAL BELL TELEPHONE LABORATORIES, INC.

Technical Industrial Intelligence Committee

May 11, 1945

DIRECTOR, AIR TECHNICAL SERVICE COMMAND
Wright Field
Dayton, Ohio

Dear Sir: Attention: Chief, Aircraft Radio Laboratories, Radio and Radar Subdivision, Engg Div., TSERR2A2

This is in reply to your letter of 4 May 1945 telling of the establishment of the Technical Industrial Intelligence Committee and of the opportunity for industrial organizations to collaborate with this committee to the end that information of technical value may be made available to United States production. Your letter under reply also offers this Company the opportunity to submit through Air Technical Service Command, technical problems to be investigated in liberated or enemy areas of Europe.

At the invitation of Mr. L. H. Peebles, Chairman of the Communications Subcommittee of the Technical Industrial Intelligence Committee, the Bell Telephone System has already designated representatives to the several Panels of the Communications Subcommittee and it had been our intention to clear questions and problems of interest to this Company through these Panel representatives. For information, these Panel representatives are as follows:

PANEL I WIRE COMMUNICATIONS SYSTEMS

Mr. F. A. Cowan, A.T.&T.Co.

PANEL II RADIO COMMUNICATIONS SYSTEMS

Mr. G. W. Gilman, B.T.L.

PANEL III RADAR SYSTEMS

Mr. R. E. Poole, B.T.L.

PANEL IV

Mr. W. H. Martin, B.T.L.

Also at the invitation of the Communications Subcommittee, we have designated two highly qualified representatives of Bell Telephone Laboratories to serve as investigators in liberated or enemy areas of Europe in this connection. It is our understanding that the Communications Subcommittee is processing these representatives through the Foreign Economic Administration for such duties in Europe. Under these circumstances, we feel that the needs of this Company in this matter are already cared for and we are accordingly not planning to take advantage of the opportunity offered by your letter under reply to present technical problems through Air Technical Service Command. We are, however, glad to cooperate with the Technical Industrial Intelligence Committee and shall appreciate receiving any reports of investigations in the communications field that can be made available to industry.

Very truly yours,

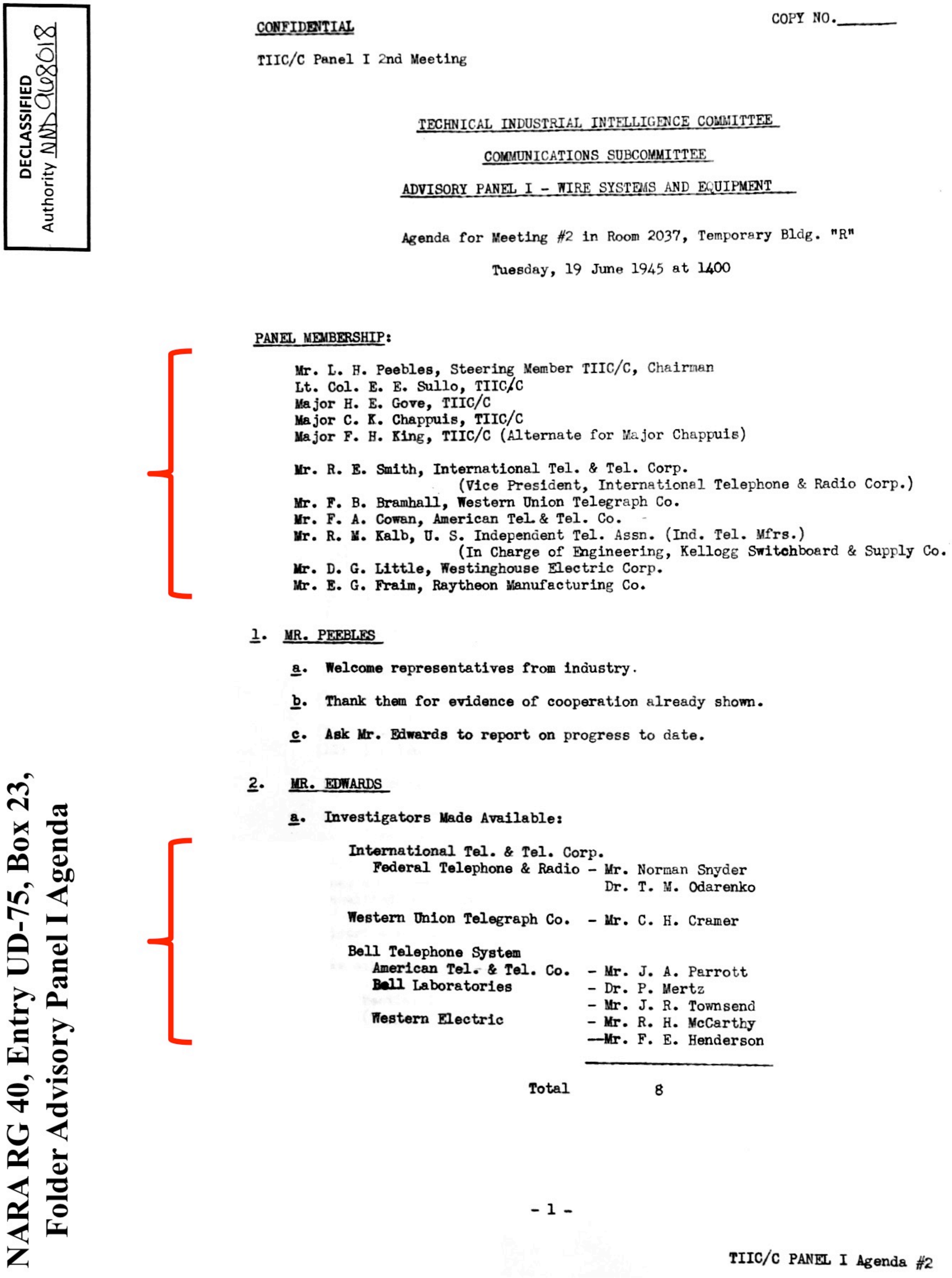
(Original Signed by
D. A. Quarles)

Director of
Apparatus Development

APPENDIX D TIIC/C Agenda #9

NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda

Figure B.245: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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TIIC/C Panel I 2nd Meeting

TECHNICAL INDUSTRIAL INTELLIGENCE COMMITTEE
COMMUNICATIONS SUBCOMMITTEE
ADVISORY PANEL I - WIRE SYSTEMS AND EQUIPMENT

Agenda for Meeting #2 in Room 2037, Temporary Bldg. "R"
Tuesday, 19 June 1945 at 1400

PANEL MEMBERSHIP:

Mr. L. H. Peebles, Steering Member TIIC/C, Chairman
Lt. Col. E. E. Sullo, TIIC/C
Major H. E. Gove, TIIC/C
Major C. K. Chappuis, TIIC/C
Major F. H. King, TIIC/C (Alternate for Major Chappuis)

Mr. R. E. Smith, International Tel. & Tel. Corp.
(Vice President, International Telephone & Radio Corp.)
Mr. F. B. Bramhall, Western Union Telegraph Co.
Mr. F. A. Cowan, American Tel. & Tel. Co.
Mr. R. M. Kalb, U. S. Independent Tel. Assn. (Ind. Tel. Mfrs.)
(In Charge of Engineering, Kellogg Switchboard & Supply Co.
Mr. D. G. Little, Westinghouse Electric Corp.
Mr. E. G. Fraim, Raytheon Manufacturing Co.

1. MR. PEEBLES

a. Welcome representatives from industry.

b. Thank them for evidence of cooperation already shown.

c. Ask Mr. Edwards to report on progress to date.

2. MR. EDWARDS

a. Investigators Made Available:

International Tel. & Tel. Corp.	
Federal Telephone & Radio	- Mr. Norman Snyder Dr. T. M. Odarenko
Western Union Telegraph Co.	- Mr. C. H. Cramer
Bell Telephone System	
American Tel. & Tel. Co.	- Mr. J. A. Parrott
Bell Laboratories	- Dr. P. Mertz - Mr. J. R. Townsend
Western Electric	- Mr. R. H. McCarthy —Mr. F. E. Henderson
Total	8

- 1 -

TIIC/C PANEL I Agenda #2

Figure B.246: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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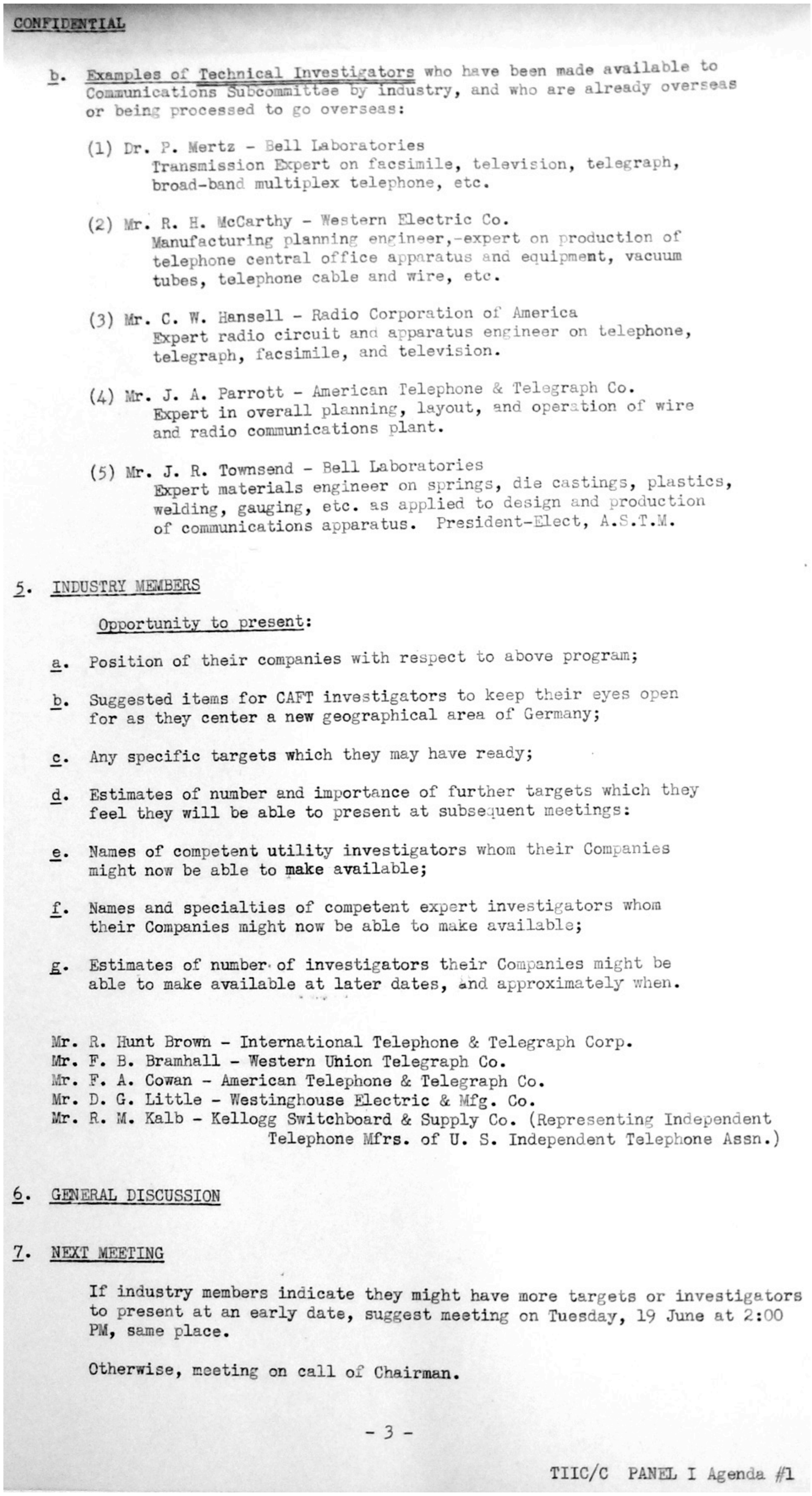

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b. Examples of Technical Investigators who have been made available to Communications Subcommittee by industry, and who are already overseas or being processed to go overseas:

(1) Dr. P. Mertz - Bell Laboratories
Transmission Expert on facsimile, television, telegraph, broad-band multiplex telephone, etc.

(2) Mr. R. H. McCarthy - Western Electric Co.
Manufacturing planning engineer,-expert on production of telephone central office apparatus and equipment, vacuum tubes, telephone cable and wire, etc.

(3) Mr. C. W. Hansell - Radio Corporation of America
Expert radio circuit and apparatus engineer on telephone, telegraph, facsimile, and television.

(4) Mr. J. A. Parrott - American Telephone & Telegraph Co.
Expert in overall planning, layout, and operation of wire and radio communications plant.

(5) Mr. J. R. Townsend - Bell Laboratories
Expert materials engineer on springs, die castings, plastics, welding, gauging, etc. as applied to design and production of communications apparatus. President-Elect, A.S.T.M.

5. INDUSTRY MEMBERS

Opportunity to present:

a. Position of their companies with respect to above program;

b. Suggested items for CAFT investigators to keep their eyes open for as they center a new geographical area of Germany;

c. Any specific targets which they may have ready;

d. Estimates of number and importance of further targets which they feel they will be able to present at subsequent meetings:

e. Names of competent utility investigators whom their Companies might now be able to make available;

f. Names and specialties of competent expert investigators whom their Companies might now be able to make available;

g. Estimates of number of investigators their Companies might be able to make available at later dates, and approximately when.

Mr. R. Hunt Brown - International Telephone & Telegraph Corp.
Mr. F. B. Bramhall - Western Union Telegraph Co.
Mr. F. A. Cowan - American Telephone & Telegraph Co.
Mr. D. G. Little - Westinghouse Electric & Mfg. Co.
Mr. R. M. Kalb - Kellogg Switchboard & Supply Co. (Representing Independent Telephone Mfrs. of U. S. Independent Telephone Assn.)

6. GENERAL DISCUSSION

7. NEXT MEETING

If industry members indicate they might have more targets or investigators to present at an early date, suggest meeting on Tuesday, 19 June at 2:00 PM, same place.

Otherwise, meeting on call of Chairman.

- 3 -

TIIC/C PANEL I Agenda #1

NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda

Figure B.247: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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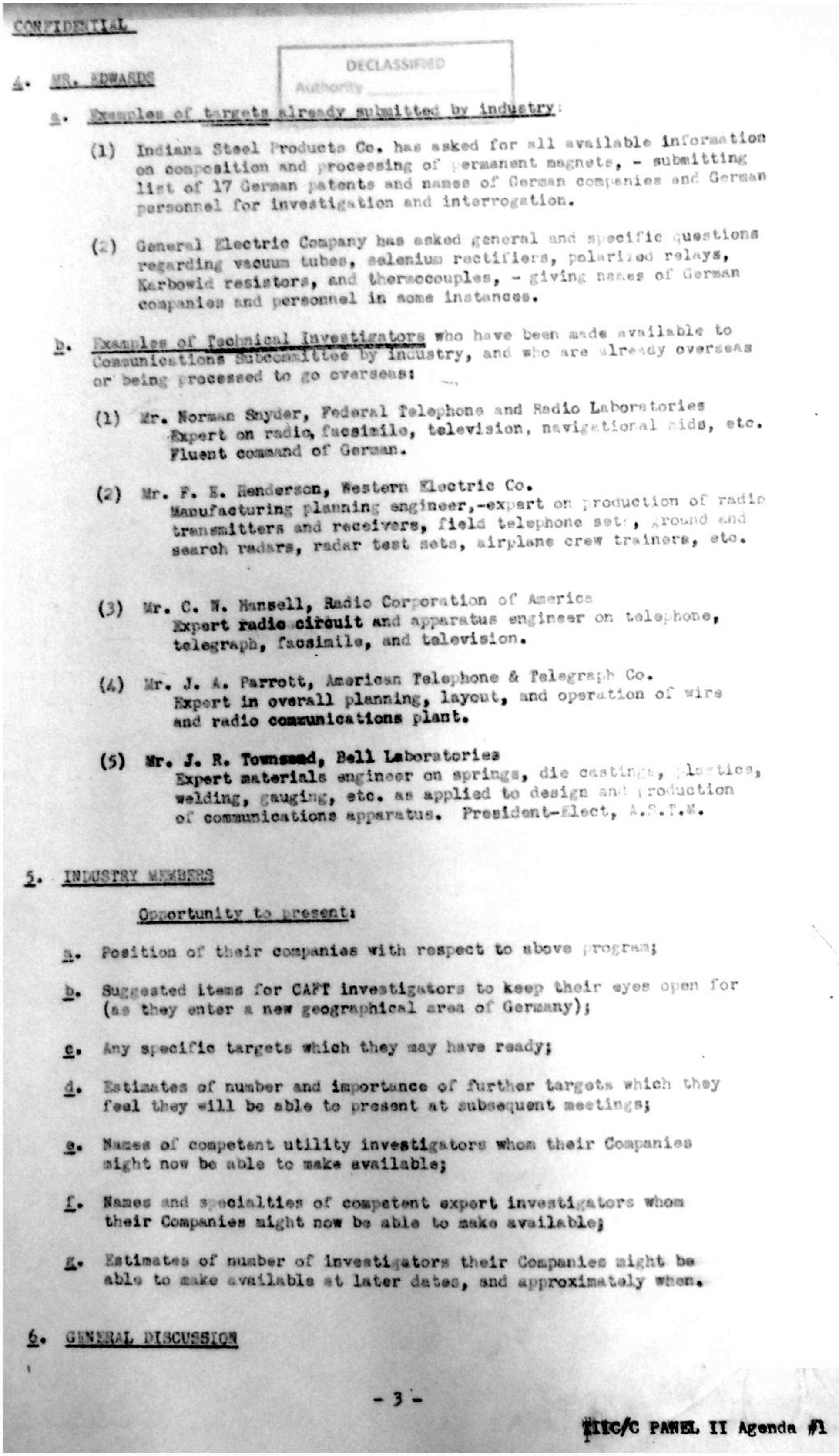

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4. MR. EDWARDS

a. Examples of targets already submitted by industry:

(1) Indiana Steel Products Co. has asked for all available information on composition and processing of permanent magnets, - submitting list of 17 German patents and names of German companies and German personnel for investigation and interrogation.

(2) General Electric Company has asked general and specific questions regarding vacuum tubes, selenium rectifiers, polarized relays, Karbowid resistors, and thermocouples, - giving names of German companies and personnel in some instances.

b. Examples of Technical Investigators who have been made available to Communications Subcommittee by industry, and who are already overseas or being processed to go overseas:

(1) Mr. Norman Snyder, Federal Telephone and Radio Laboratories
Expert on radio, facsimile, television, navigational aids, etc.
Fluent command of German.

(2) Mr. F. E. Henderson, Western Electric Co.
Manufacturing planning engineer,-expert on production of radio transmitters and receivers, field telephone sets, ground and search radars, radar test sets, airplane crew trainers, etc.

(3) Mr. C. W. Hansell, Radio Corporation of America
Expert radio circuit and apparatus engineer on telephone, telegraph, facsimile, and television.

(4) Mr. J. A. Parrott, American Telephone & Telegraph Co.
Expert in overall planning, layout, and operation of wire and radio communications plant.

(5) Mr. J. R. Townsend, Bell Laboratories
Expert materials engineer on springs, die castings, plastics, welding, gauging, etc. as applied to design and production of communications apparatus. President-Elect, A.S.T.M.

5. INDUSTRY MEMBERS

Opportunity to present:

a. Position of their companies with respect to above program;

b. Suggested items for CAFT investigators to keep their eyes open for (as they enter a new geographical area of Germany);

c. Any specific targets which they may have ready;

d. Estimates of number and importance of further targets which they feel they will be able to present at subsequent meetings;

e. Names of competent utility investigators whom their Companies might now be able to make available;

f. Names and specialties of competent expert investigators whom their Companies might now be able to make available;

g. Estimates of number of investigators their Companies might be able to make available at later dates, and approximately when.

6. GENERAL DISCUSSION

- 3 -

TIIC/C PANEL II Agenda #1

NARA RG 40, Entry UD-75, Box 23,
Folder Advisory Panel II Agenda

Figure B.248: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel II Agenda]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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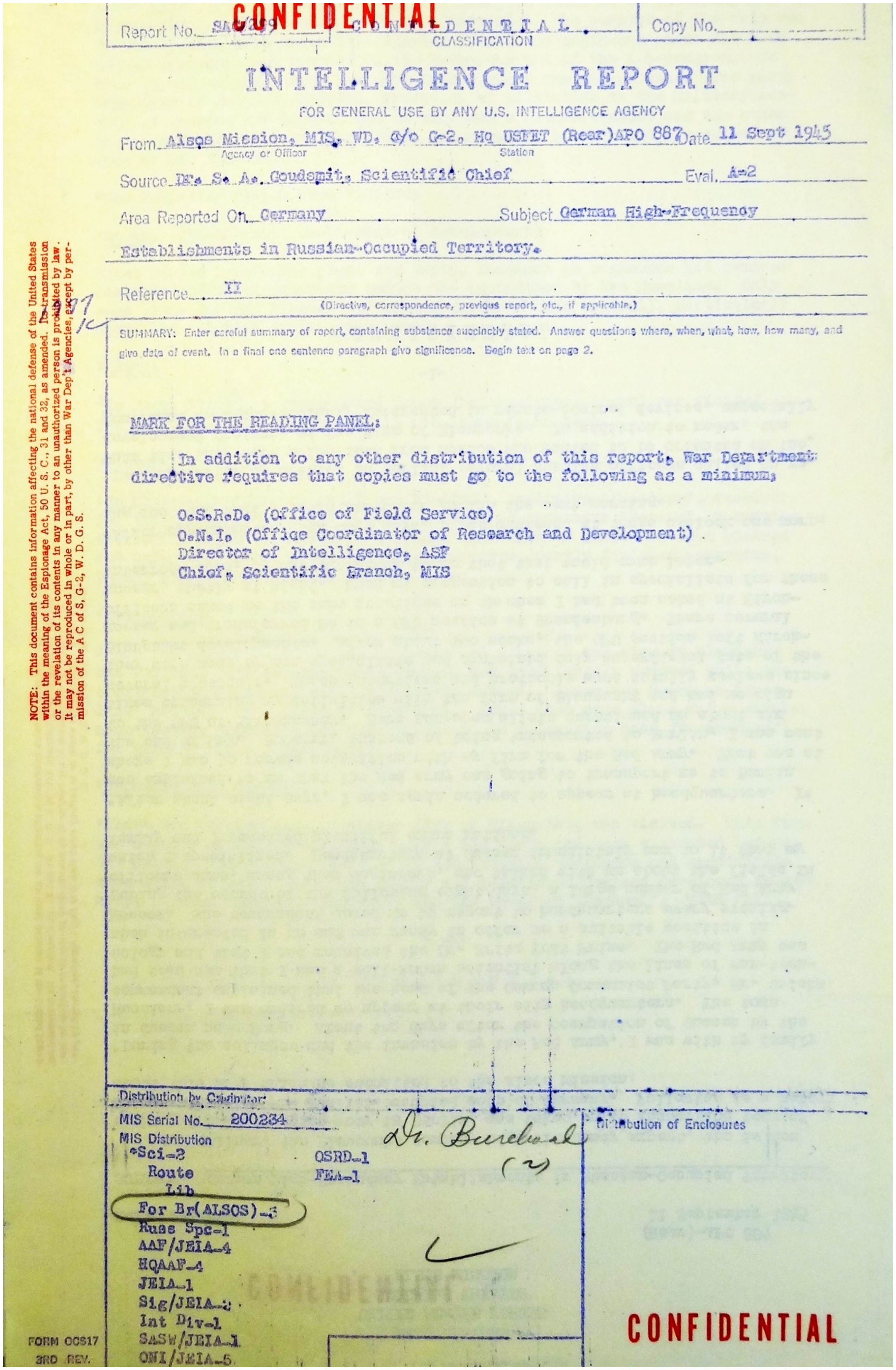
NARA RG 77, Entry UD-22A,
Box 165, Folder ALSOS MATERIAL



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Report No. SA[illegible] C O N F I D E N T I A L . Copy No.
CLASSIFICATION

INTELLIGENCE REPORT

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From Alsos Mission, MIS, WD, c/o G-2, Hq USFET (Rear) APO 887 Date 11 Sept 1945
Agency or Officer Station

Source Dr. S. A. Goudsmit, Scientific Chief Eval. A-2

Area Reported On Germany Subject German High-Frequency Establishments in Russian-Occupied Territory.

Reference II
(Directive, correspondence, previous report, etc., if applicable.)

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SUMMARY: Enter careful summary of report, containing substance succinctly stated. Answer questions where, when, what, how, how many, and give date of event. In a final one sentence paragraph give significance. Begin text on page 2.

MARK FOR THE READING PANEL:

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Figure B.249: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

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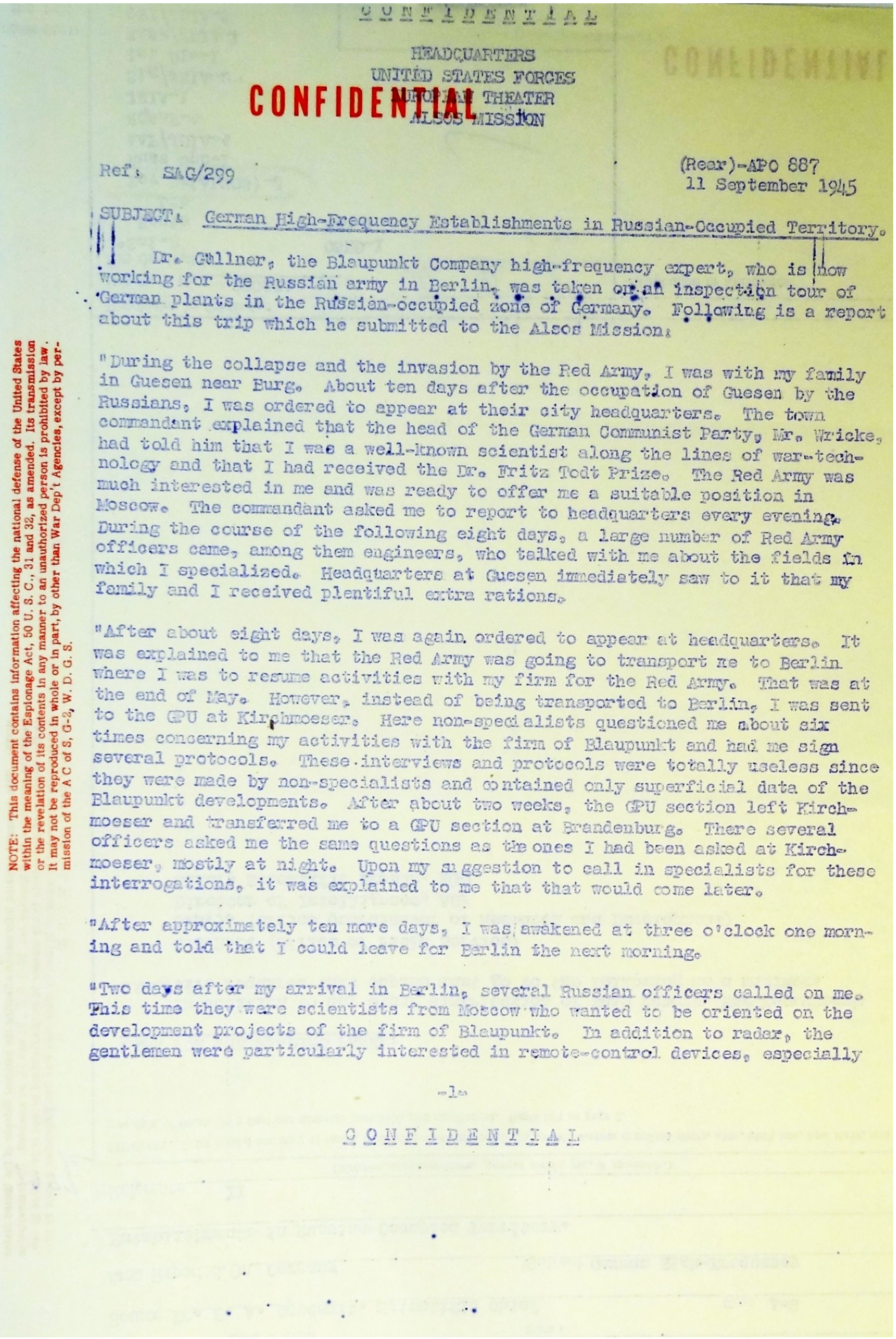

C O N F I D E N T I A L

HEADQUARTERS
UNITED STATES FORCES
EUROPEAN THEATER
ALSOS MISSION

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Ref: SAG/299

(Rear)-APO 887
11 September 1945

SUBJECT: German High-Frequency Establishments in Russian-Occupied Territory.

Dr. Güllner, the Blaupunkt Company high-frequency expert, who is now working for the Russian army in Berlin, was taken on an inspection tour of German plants in the Russian-occupied zone of Germany. Following is a report about this trip which he submitted to the Alsos Mission:

"During the collapse and the invasion by the Red Army, I was with my family in Guesen near Burg. About ten days after the occupation of Guesen by the Russians, I was ordered to appear at their city headquarters. The town commandant explained that the head of the German Communist Party, Mr. Wricke, had told him that I was a well-known scientist along the lines of war-technology and that I had received the Dr. Fritz Todt Prize. The Red Army was much interested in me and was ready to offer me a suitable position in Moscow. The commandant asked me to report to headquarters every evening. During the course of the following eight days, a large number of Red Army officers came, among them engineers, who talked with me about the fields in which I specialized. Headquarters at Guesen immediately saw to it that my family and I received plentiful extra rations.

"After about eight days, I was again ordered to appear at headquarters. It was explained to me that the Red Army was going to transport me to Berlin where I was to resume activities with my firm for the Red Army. That was at the end of May. However, instead of being transported to Berlin, I was sent to the GPU at Kirchmoeser. Here non-specialists questioned me about six times concerning my activities with the firm of Blaupunkt and had me sign several protocols. These interviews and protocols were totally useless since they were made by non-specialists and contained only superficial data of the Blaupunkt developments. After about two weeks, the GPU section left Kirchmoeser and transferred me to a GPU section at Brandenburg. There several officers asked me the same questions as the ones I had been asked at Kirchmoeser, mostly at night. Upon my suggestion to call in specialists for these interrogations, it was explained to me that that would come later.

"After approximately ten more days, I was awakened at three o'clock one morning and told that I could leave for Berlin the next morning.

"Two days after my arrival in Berlin, several Russian officers called on me. This time they were scientists from Moscow who wanted to be oriented on the development projects of the firm of Blaupunkt. In addition to radar, the gentlemen were particularly interested in remote-control devices, especially

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C O N F I D E N T I A L

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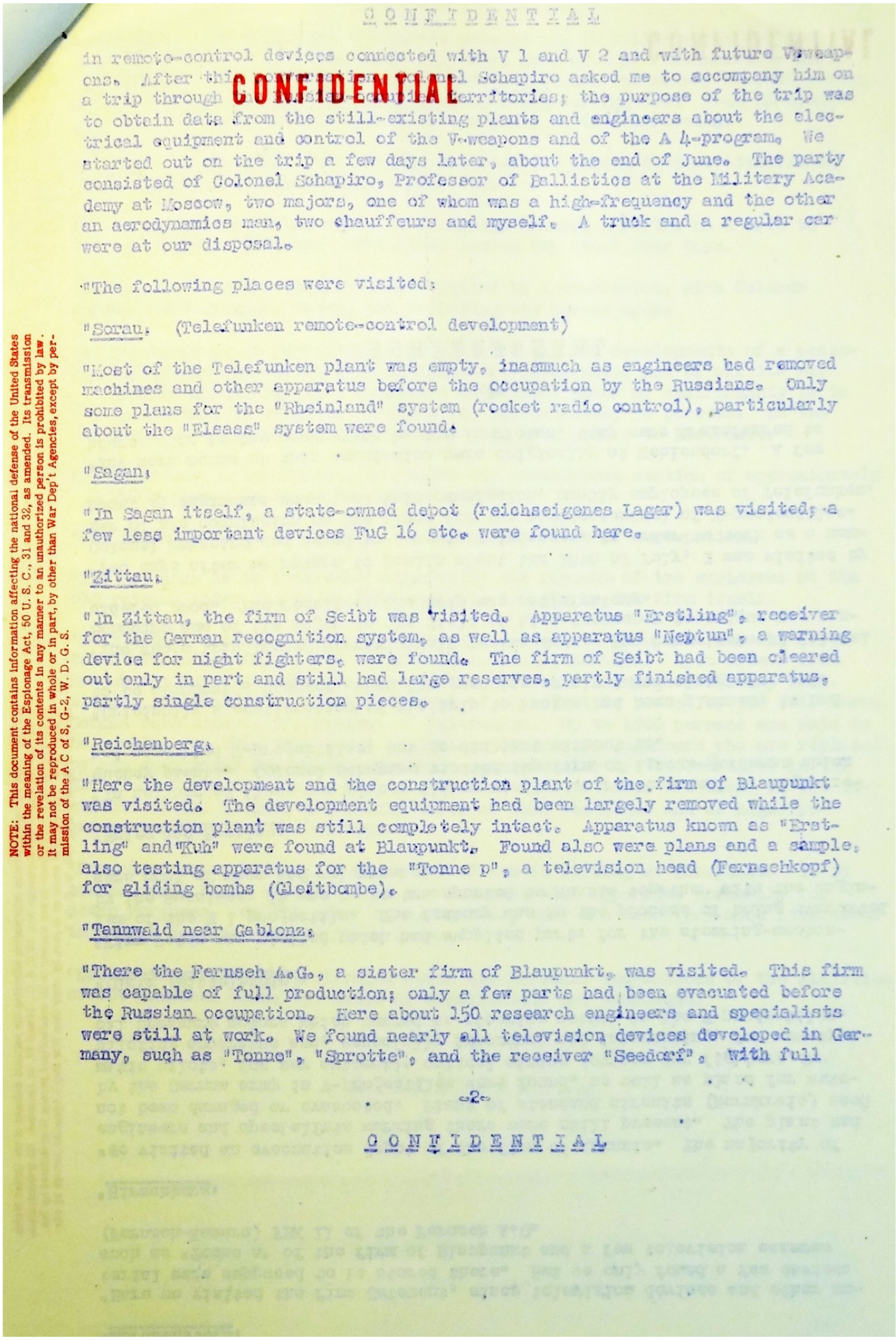
NARA RG 77, Entry UD-22A,
Box 165, Folder ALSOS MATERIAL

Figure B.250: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

NARA RG 77, Entry UD-22A,
Box 165, Folder ALSOS MATERIAL



C O N F I D E N T I A L

in remote-control devices connected with V 1 and V 2 and with future V-weapons. After this conversation Colonel Schapiro asked me to accompany him on a trip through the Russian-occupied territories; the purpose of the trip was to obtain data from the still-existing plants and engineers about the electrical equipment and control of the V-weapons and of the A 4-program. We started out on the trip a few days later, about the end of June. The party consisted of Colonel Schapiro, Professor of Ballistics at the Military Academy at Moscow, two majors, one of whom was a high-frequency and the other an aerodynamics man, two chauffeurs and myself. A truck and a regular car were at our disposal.

"The following places were visited:

"Sorau: (Telefunken remote-control development)

"Most of the Telefunken plant was empty, inasmuch as engineers had removed machines and other apparatus before the occupation by the Russians. Only some plans for the "Rheinland" system (rocket radio control), particularly about the "Elsass" system were found.

"Sagan:

"In Sagan itself, a state-owned depot (reichseigenes Lager) was visited; a few less important devices FuG 16 etc. were found here.

"Zittau:

"In Zittau, the firm of Seibt was visited. Apparatus "Erstling", receiver for the German recognition system, as well as apparatus "Neptun", a warning device for night fighters, were found. The firm of Seibt had been cleared out only in part and still had large reserves, partly finished apparatus, partly single construction pieces.

"Reichenberg:

"Here the development and the construction plant of the firm of Blaupunkt was visited. The development equipment had been largely removed while the construction plant was still completely intact. Apparatus known as "Erstling" and "Kuh" were found at Blaupunkt. Found also were plans and a sample, also testing apparatus for the "Tonne p", a television head (Fernsehkopf) for gliding bombs (Gleitbombe).

"Tannwald near Gablonz:

"There the Fernseh A.G., a sister firm of Blaupunkt, was visited. This firm was capable of full production; only a few parts had been evacuated before the Russian occupation. Here about 150 research engineers and specialists were still at work. We found nearly all television devices developed in Germany, such as "Tonne", "Sprotte", and the receiver "Seedorf", with full

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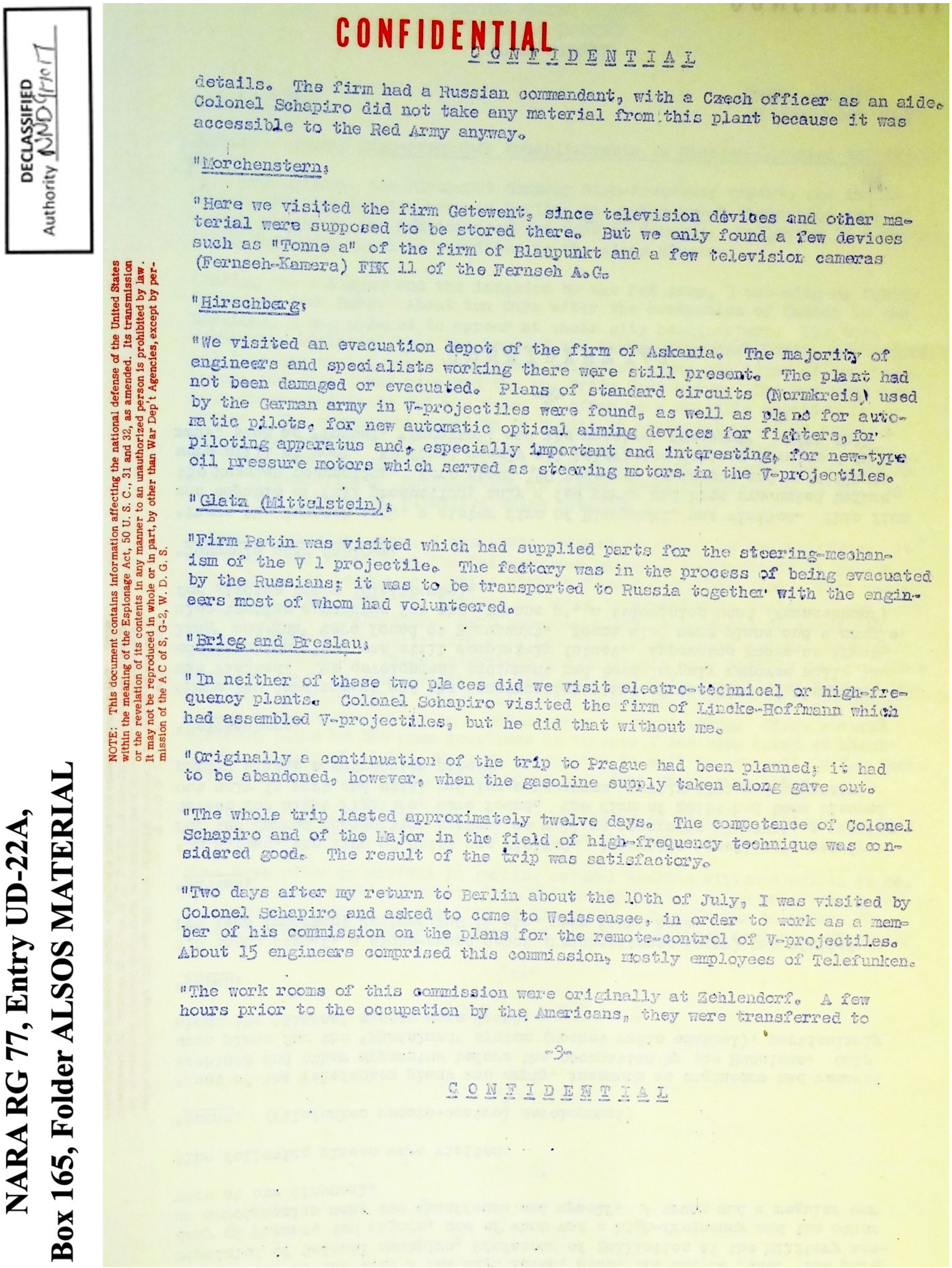
Figure B.251: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].



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details. The firm had a Russian commandant, with a Czech officer as an aide. Colonel Schapiro did not take any material from this plant because it was accessible to the Red Army anyway.

"Morchenstern:

"Here we visited the firm Getewent, since television devices and other material were supposed to be stored there. But we only found a few devices such as "Tonne a" of the firm of Blaupunkt and a few television cameras (Fernseh-Kamera) FHK 11 of the Fernseh A.G.

"Hirschberg:

"We visited an evacuation depot of the firm of Askania. The majority of engineers and specialists working there were still present. The plant had not been damaged or evacuated. Plans of standard circuits (Normkreis) used by the German army in V-projectiles were found, as well as plans for automatic pilots, for new automatic optical aiming devices for fighters, for piloting apparatus and, especially important and interesting, for new-type oil pressure motors which served as steering motors in the V-projectiles.

"Glatz (Mittelstein):

"Firm Patin was visited which had supplied parts for the steering-mechanism of the V 1 projectile. The factory was in the process of being evacuated by the Russians; it was to be transported to Russia together with the engineers most of whom had volunteered.

"Brieg and Breslau:

"In neither of these two places did we visit electro-technical or high-frequency plants. Colonel Schapiro visited the firm of Lincke-Hoffmann which had assembled V-projectiles, but he did that without me.

"Originally a continuation of the trip to Prague had been planned; it had to be abandoned, however, when the gasoline supply taken along gave out.

"The whole trip lasted approximately twelve days. The competence of Colonel Schapiro and of the Major in the field of high-frequency technique was considered good. The result of the trip was satisfactory.

"Two days after my return to Berlin about the 10th of July, I was visited by Colonel Schapiro and asked to come to Weissensee, in order to work as a member of his commission on the plans for the remote-control of V-projectiles. About 15 engineers comprised this commission, mostly employees of Telefunken.

"The work rooms of this commission were originally at Zehlendorf. A few hours prior to the occupation by the Americans, they were transferred to

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NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL

Figure B.252: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

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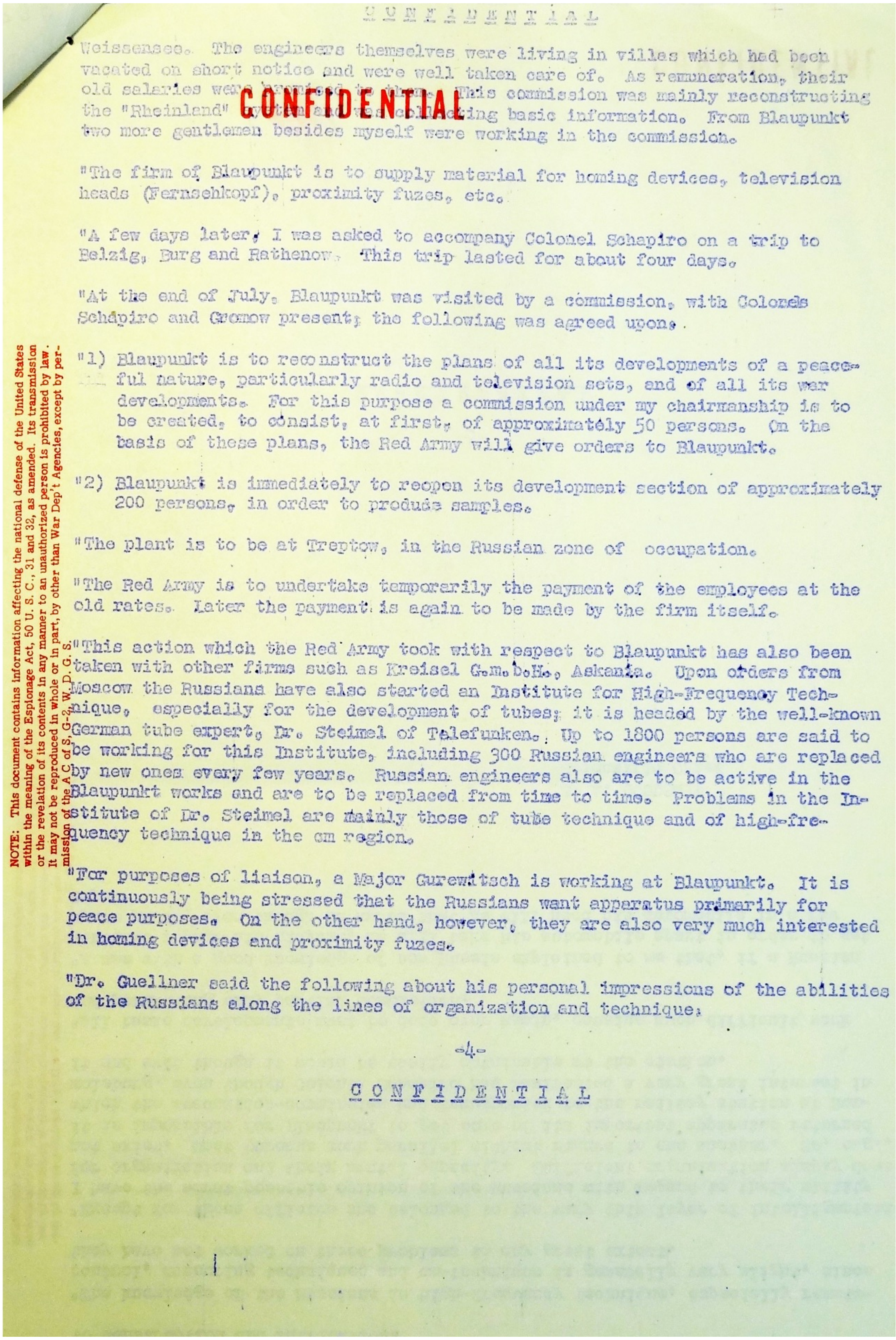

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Weissensee. The engineers themselves were living in villas which had been vacated on short notice and were well taken care of. As remuneration, their old salaries were promised to them. This commission was mainly reconstructing the "Rheinland" system and was collecting basic information. From Blaupunkt two more gentlemen besides myself were working in the commission.

"The firm of Blaupunkt is to supply material for homing devices, television heads (Fernsehkopf), proximity fuzes, etc.

"A few days later, I was asked to accompany Colonel Schapiro on a trip to Belzig, Burg and Rathenow. This trip lasted for about four days.

"At the end of July, Blaupunkt was visited by a commission, with Colonels Schapiro and Gromow present; the following was agreed upon.

"1) Blaupunkt is to reconstruct the plans of all its developments of a peaceful nature, particularly radio and television sets, and of all its war developments. For this purpose a commission under my chairmanship is to be created, to consist, at first, of approximately 50 persons. On the basis of these plans, the Red Army will give orders to Blaupunkt.

"2) Blaupunkt is immediately to reopen its development section of approximately 200 persons, in order to produce samples.

"The plant is to be at Treptow, in the Russian zone of occupation.

"The Red Army is to undertake temporarily the payment of the employees at the old rates. Later the payment is again to be made by the firm itself.

"This action which the Red Army took with respect to Blaupunkt has also been taken with other firms such as Kreisel G.m.b.H., Askania. Upon orders from Moscow the Russians have also started an Institute for High-Frequency Technique, especially for the development of tubes; it is headed by the well-known German tube expert, Dr. Steimel of Telefunken. Up to 1800 persons are said to be working for this Institute, including 300 Russian engineers who are replaced by new ones every few years. Russian engineers also are to be active in the Blaupunkt works and are to be replaced from time to time. Problems in the Institute of Dr. Steimel are mainly those of tube technique and of high-frequency technique in the cm region.

"For purposes of liaison, a Major Gurewitsch is working at Blaupunkt. It is continuously being stressed that the Russians want apparatus primarily for peace purposes. On the other hand, however, they are also very much interested in homing devices and proximity fuzes.

"Dr. Guellner said the following about his personal impressions of the abilities of the Russians along the lines of organization and technique:

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NARA RG 77, Entry UD-22A,
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Figure B.253: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

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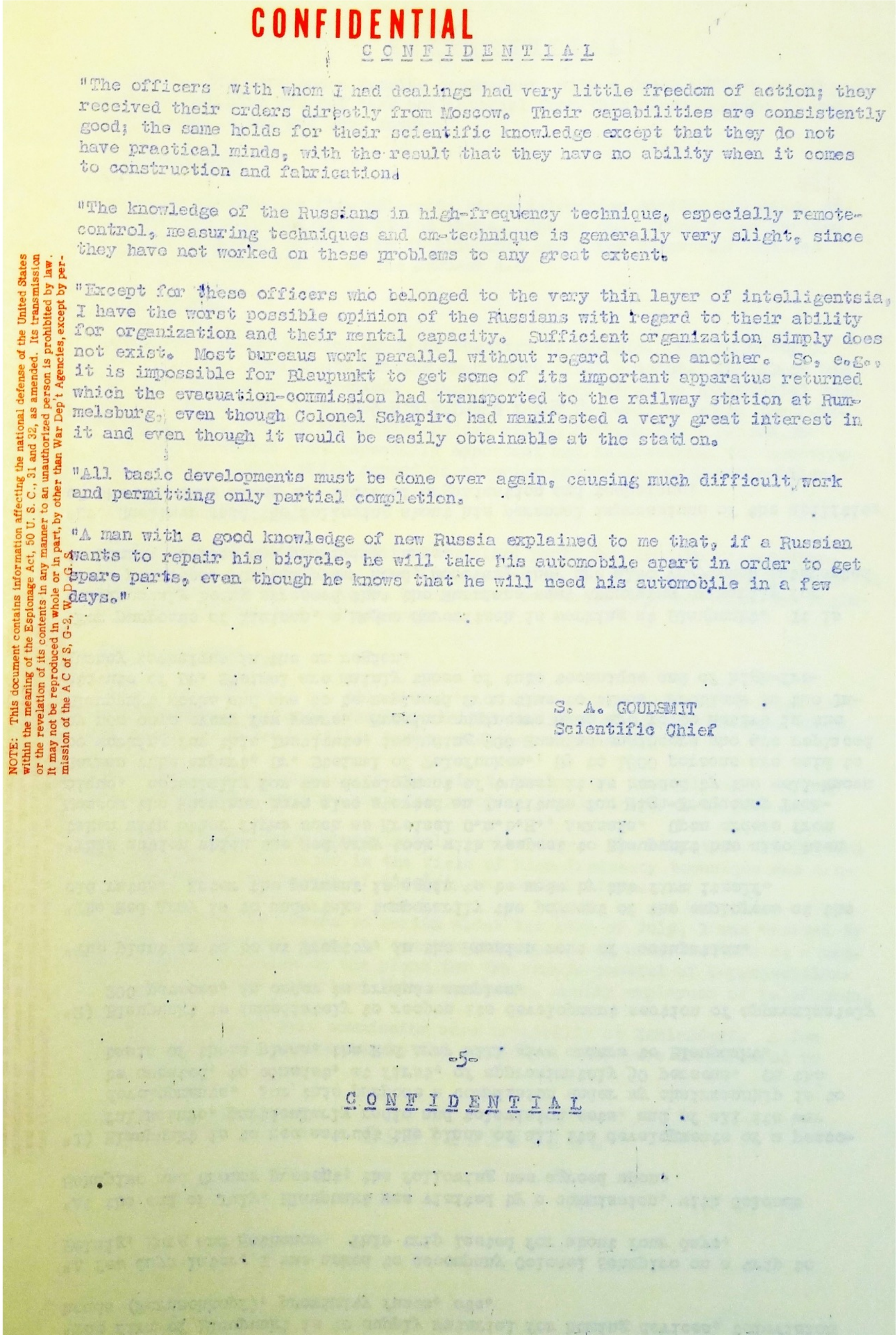

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"The officers with whom I had dealings had very little freedom of action; they received their orders directly from Moscow. Their capabilities are consistently good; the same holds for their scientific knowledge except that they do not have practical minds, with the result that they have no ability when it comes to construction and fabrication.

"The knowledge of the Russians in high-frequency technique, especially remote-control, measuring techniques and cm-technique is generally very slight, since they have not worked on these problems to any great extent.

"Except for these officers who belonged to the very thin layer of intelligentsia, I have the worst possible opinion of the Russians with regard to their ability for organization and their mental capacity. Sufficient organization simply does not exist. Most bureaus work parallel without regard to one another. So, e.g., it is impossible for Blaupunkt to get some of its important apparatus returned which the evacuation-commission had transported to the railway station at Rummelsburg, even though Colonel Schapiro had manifested a very great interest in it and even though it would be easily obtainable at the station.

"All basic developments must be done over again, causing much difficult work and permitting only partial completion.

"A man with a good knowledge of new Russia explained to me that, if a Russian wants to repair his bicycle, he will take his automobile apart in order to get spare parts, even though he knows that he will need his automobile in a few days."

S. A. GOUDSMIT
Scientific Chief

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C O N F I D E N T I A L

NARA RG 77, Entry UD-22A,
Box 165, Folder ALSOS MATERIAL

Figure B.254: Account from a German electrical engineer regarding some former German advanced electronics facilities that were now in Soviet-controlled territory [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Klaus-Dietmar Henke. 2015. *Die amerikanische Besetzung Deutschlands.* 2nd ed. Berlin: De Gruyter. pp. 754–758. https://books.google.com/books?id=J73yCQAAQBAJ

Ebenfalls im Mai hatte sich, wie gezeigt, in der Truman-Administration trotz der massiven Einwände Churchills die übereinstimmende Auffassung herauskristallisiert, die amerikanischen Truppen müßten auf jeden Fall in Kürze aus der künftigen sowjetischen Besatzungszone in Mitteldeutschland abgezogen werden. Von Mitte Juni datiert das Telegramm, in dem der amerikanische Präsident dies Stalin mitteilte.[310] Entsprechend zielstrebig ging die Army in Mitteldeutschland vor. Am 25. Mai erfolgte die Weisung an das Ordnance Technical Intelligence Team im Harz, die dortigen Spezialisten samt ihren Familien so weit nach Westen wegzuführen, daß sie mit Sicherheit unter amerikanischer Kontrolle bleiben würden.[311] Bald darauf korrespondierten Eisenhower und Marshall über die Lage im Raum Nordhausen, die Phantasie und Energie der T-Forces so gefangennahm. Dabei verwies der Oberbefehlshaber darauf, daß die Intelligence Teams ihre Arbeit in den unterirdischen Produktionsstätten für Raketen nirgends auch nur annähernd abgeschlossen hätten.[312] Obwohl Eisenhower es nicht erwähnte, galt diese Feststellung natürlich erst recht für die übrigen wissenschaftlich-technischen Objekte in Sachsen und Thüringen, die ebenfalls kriegswichtig, aber weniger spektakulär und deshalb nicht alle von Anfang an mit demselben Nachdruck ausgeforscht worden waren.

Also in May, as shown, the consensus view had emerged in the Truman administration, despite Churchill's massive objections, that American troops would have to be withdrawn from the future Soviet occupation zone in central Germany in any case in the near future. The telegram in which the American president communicated this to Stalin dates from mid-June.[310] The Army proceeded with corresponding determination in central Germany. On May 25, instructions were given to the Ordnance Technical Intelligence team in the Harz Mountains to move the specialists there, together with their families, so far west that they would certainly remain under American control.[311] Soon thereafter, Eisenhower and Marshall corresponded about the situation in the Nordhausen area, which so captured the imagination and energy of the T-Forces. In doing so, the commander in chief pointed out that the intelligence teams had nowhere even remotely completed their work in the underground production facilities for rockets.[312] Although Eisenhower did not mention it, this observation naturally applied a fortiori to the other scientific and technical facilities in Saxony and Thuringia, which were also important to the war effort but less spectacular and therefore had not all been explored with the same vigor from the beginning.

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[310] Vgl. Eisenhower-Papers, VI/4.

[311] Lasby, Paperclip, S. 43.

[312] Telegramm Eisenhowers an Marshall v. 7. 6. 1945; Eisenhower-Papers, VI, S. 143 ff.

[310] Cf. Eisenhower Papers, VI/4.

[311] Lasby, Paperclip, p. 43.

[312] Eisenhower's telegram to Marshall v. 7. 6. 1945; Eisenhower Papers, VI, p. 143 ff.

Dieser ärgerliche Umstand mag Eisenhower zwei Tage zuvor besonders schmerzlich bewußt geworden sein, als beim ersten Zusammentreffen der Militärgouverneure in Berlin in aller wünschenswerten Klarheit herauskam, daß die Räumung der sowjetischen Besatzungszone unmöglich noch länger hinausgeschoben werden konnte. Das steigerte die Hektik der allierten T-Forces noch, deren detektivisch-kriminalistische Arbeit überall, aber besonders in Mitteldeutschland, unter einem beträchtlichen Zeit- und Konkurrenzdruck durchgeführt werden mußte. Im Juni steigerte sich die Hektik der Intelligence Teams, die in den überaus ergiebigen, bald zu übergebenden Gebieten noch längst nicht alles unter Dach und Fach hatten, zu kopfloser Hast. Unmittelbar nachdem Truman den britischen Premierminister und Stalin von dem bevorstehenden Rückzug seiner Truppen in Kenntnis gesetzt hatte, erließ das Allierte Oberkommando in Einklang mit der militärischen Führung in Washington am 18. und 19. Juni 1945 die streng geheimen Befehle, beim Abzug alle jene deutschen Wissenschaftler und Techniker zu “evakuieren”, deren Fähigkeiten und Kenntnisse Großbritannien und die Vereinigten Staaten nutzen wollten.[313]

Eisenhower may have become particularly painfully aware of this annoying circumstance two days earlier when, at the first meeting of the military governors in Berlin, it emerged with all desirable clarity that the evacuation of the Soviet occupied zone could not possibly be postponed any longer. This increased the hectic pace of the Allied T-Forces, whose detective-criminal work had to be carried out everywhere, but especially in central Germany, under considerable time and competitive pressure. In June, the hectic pace of the intelligence teams, who were far from having everything under control in the extremely productive areas soon to be handed over, increased to headlong haste. Immediately after Truman notified the British prime minister and Stalin of the impending withdrawal of his forces, the Allied High Command, in concert with the military leadership in Washington, issued top-secret orders on 18 and 19 June 1945 to “evacuate” on withdrawal all those German scientists and technicians whose skills and knowledge Britain and the United States wished to use.[313]

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[313] Die Daten dieser Befehle (SHAEF, GBI/FIAT/322-21/1) gehen aus einem Schreiben des Chefs von FIAT an den Kommandierenden General von USFET, ACOS G-5, v. 16. 7. 1945 hervor (“Evacuation of German Scientists from Area now under Russian Occupation”); NA, RG 260, 17/11-1. Gimbel, U.S. and German Scientists, S. 438, nennt als Datum des Befchls den 15. Juni.

[313] The dates of these orders (SHAEF, GBI/FIAT/322-21/1) come from a letter from the chief of FIAT to the commanding general of USFET, ACOS G-5, v. 16 July 1945 (“Evacuation of German Scientists from Area now under Russian Occupation”); NARA, RG 260, 17/11-1. Gimbel, U.S. and German Scientists, p. 438, gives the date of the order as 15 June.

Es begann, was ein Offizier der Air Force als “Griff in die russische Zone” titulierte.[314] Zum zentralen Streitpunkt zwischen den USA und der Sowjetunion sollte bald die Frage werden, ob dabei Gewalt angewandt worden sei oder nicht. Obwohl die Amerikaner dies immer entrüstet abstritten, beharrten die Russen völlig zu Recht darauf, daß es keine einfache Evakuierung, sondern eine Zwangsevakuierung gewesen sei, die die U.S. Army bei ihrem Abzug aus Sachsen und Thüringen in Szene gesetzt habe. Tatsächlich gab es kaum eine Fabrik von technologischer Bedeutung, kaum ein naturwissenschaftliches Institut, das die Amerikaner vor ihrem Abrücken aus Mitteldeutschland nicht durchkämmt hätten, auch kaum einen Experten von Rang, den das CIC und die T-Forces in den beiden letzten Juniwochen nicht zur Abreise in den Westen aufgefordert, gedrängt, genötigt oder gezwungen hätten.

There began what one Air Force officer dubbed a “reach into the Russian zone.”[314] The central point of contention between the United States and the Soviet Union would soon become whether or not force had been used in the process. Although the Americans always indignantly denied this, the Russians quite rightly insisted that it was not a simple evacuation but a forced evacuation that the U.S. Army had staged during its withdrawal from Saxony and Thuringia. In fact, there was hardly a factory of technological importance, hardly a scientific institute that the Americans had not combed before their departure from central Germany, and hardly an expert of rank whom the CIC and the T-Forces had not asked, urged, coerced or forced to leave for the West in the last two weeks of June.

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[314] Lasby, Paperclip, S. 29.

[314] Lasby, Paperclip, p. 29.

Bei Siemens & Halske im thüringischen Arnstadt wurde es am 21. Juni ernst.[315] Am Abend dieses Tages suchten zwei amerikanische Offiziere der 102nd Infantry Division Direktor Lohse in seiner Privatwohnung auf, stellen ihm zunächst einige allgemeine Fragen zur Firmenorganisation, zu den führenden Persönlichkeiten der mitteldeutschen Elektroindustrie (über die sie offenbar Dossiers hatten) und lenkten dann auf den Siemens-Anteil an der V-Waffenproduktion über. Seine Firma habe bestimmte elektrotechnische Bauelemente zugeliefert, erläuterte der für die thüringischen Fabriken bevollmächtigle Siemens-Manager, der nicht zum ersten Mal einer allierten Expertenkommission Rede und Antwort stehen mußte. Doch dann machten ihm die beiden Offiziere einige höchst überraschende Eröffnungen: "Das amerikanische Hauptquartier beabsichtige, im Westen oder Südwesten, jedenfalls nicht in Thüringen, eine Fabrik, die unsere Fertigungen umfassen solle, aufzuziehen", beschrieb Lohse einige Monate später diese Unterredung. Der endgültige Standort sei ihnen selbst nicht bekannt, sagten die beiden Amerikaner weiter: "Die Fabrik gehöre zunächst keineswegs mehr zu Siemens, sondern unterstände unmittelbar dem Hauptquartier. Es würde aber denkbar sein, daß nach einer gewissen Zeit Fühlungnahme mit den westlichen Siemens-Fabriken möglich sei."[316]

At Siemens & Halske in Arnstadt, Thuringia, things got serious on June 21.[315] On the evening of that day, two American officers of the 102nd Infantry Division visited Director Lohse in his private apartment, first asked him some general questions about the company's organization, about the leading figures in the Central German electrical industry (about whom they apparently had dossiers), and then turned their attention to Siemens' share in the production of V weapons. His company had supplied certain electrotechnical components, explained the Siemens manager authorized for the Thuringian factories, who had not for the first time had to answer the questions of an Allied expert commission. But then the two officers made some highly surprising revelations to him: "The American headquarters intends to set up a factory in the west or southwest, at any rate not in Thuringia, which is to include our production facilities," Lohse described this conversation a few months later. The final location was not known to them themselves, the two Americans went on to say: "The factory would initially no longer belong to Siemens at all, but would be under the direct control of headquarters. It would be conceivable, however, that after a certain period of time, contact could be made with the Siemens factories in the West."[316]

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[315] Zur Situation dieses Zweigbetriebes in den Monaten zuvor vgl. VI/4.

[316] "Persönlicher Bericht über die Zeit von Ende März 1945 bis Ende November 1945" (mit Nachträgen von Anfang 1946), verfaßt von Direktor Adolf Lohse in Erlangen am 21. 11. 1945, dessen Richtigkeit von vier seiner leitenden Mitarbeiter durch Unterschrift bestätigt war; Siemens-Archiv, S AA 11.43/Lm 394, von Witzleben.

[315] For the situation of this branch in the months before, see VI/4.

[316] "Personal report on the period from the end of March 1945 to the end of November 1945" (with addenda from the beginning of 1946), written by Director Adolf Lohse in Erlangen on 21 Nov. 1945, the accuracy of which was confirmed by signature of four of his senior staff; Siemens Archives, S AA 11.43/Lm 394, von Witzleben.

Das war starker Tobak, der dem ahnungslosen Siemens-Direktor, welcher eben die Pläne für die Neuorganisation der mitteldeutschen Konzernbetriebe fertig hatte, mit dieser schon auf den ersten Blick ziemlich unglaubhaft klingenden Mitteilung verabreicht wurde. Er erkundigte sich deshalb auch sofort bei seinen Gästen, ob die Spitzenkräfte der thüringischen Betriebe freiwillig oder zwangsweise an den neuen Standort übersiedeln sollten. Lohse war natürlich vom ersten Augenblick an klar, daß ein für das Firmenschicksal derart einschneidender Schritt unmöglich von einem Tag auf den anderen und keinesfalls ohne Abstimmung zumindest mit Ernst von Siemens in München getan werden konnte. Seine beiden späten Besucher beeilten sich zwar zu beteuern, daß es sich "selbstverständlich" um eine freiwillige Ubersiedlung handele, andererseits verlangten die Offiziere aber "kategorisch", daß "die betr. Siemens-Herren ihre Familien an den fraglichen Ort mitnehmen müßten und daß der Abtransport binnen 48 Std. zu erfolgen habe". Schmackhaft gemacht wurde dieses Ultimatum durch das Versprechen, es stünden für die Familien "völlig eingerichtete Wohnungen" zur Verfügung, für Ernährung, Bekleidung und Erziehung der Kinder sorge das Hauptquartier.

"Als ich den Zusagen gegenüber leichte Zweifel äußerte", hielt der Direktor in seinem Rechenschaftsbericht später fest, "antwortete Mr. Ernest sehr empört, daß ich bedenken möge, daß noch nie eine deutsche Regierung ein derartig faires Angebot an Angehörige eines besiegten Volkes gemacht habe. Ich möchte in dieser Beziehung mich doch insbesondere an die Konzentrationslager, die sie auch in Thüringen vorgefunden hätten, rinnern." Direktor Lohse bekam Zeit bis 8.30 Uhr am nächsten Morgen, um die Mitarbeiter zu benennen, die ihn begleiten sollten. Auch sein Hinweis, er sei Kaufmann und kein Techniker und komme deshalb selbst wohl nicht für den geplanten Abtransport in Frage, fruchtete nichts. Das sei ihnen bekannt, verabschiedeten sich die beiden Offiziere, aber aufgrund ihrer Informationen über seine Person müßten sie Wert darauf legen, daß er den "vom Hauptquartier gewünschten Betrieb unbedingt selbst in die Hand nähme".

This was strong stuff, which the unsuspecting Siemens director, who had just finished the plans for the reorganization of the central German group companies, was presented with this announcement, which sounded quite unbelievable even at first glance. He therefore immediately inquired of his guests whether the top employees of the Thuringian plants were to move to the new location voluntarily or forcibly. Of course, it was clear to Lohse from the very first moment that such a drastic step for the fate of the company could not possibly be taken from one day to the next and under no circumstances without at least consulting Ernst von Siemens in Munich. His two late visitors hastened to affirm that it was "of course" a voluntary resettlement, but on the other hand the officers demanded "categorically" that "the Siemens men concerned must take their families with them to the place in question and that the removal must take place within 48 hours." This ultimatum was made palatable by the promise that "completely furnished apartments" would be available for the families, and that the headquarters would provide food, clothing, and education for the children.

"When I expressed slight doubts about the promises," the director later stated in his report, "Mr. Ernest replied very indignantly that I should remember that no German government had ever made such a fair offer to members of a defeated people. In this respect, I would like to recall in particular the concentration camps which they had also found in Thuringia." Director Lohse was given until 8:30 the next morning to name the staff members who were to accompany him. His comment that he was a merchant and not a technician, and that he himself was therefore probably not eligible for the planned removal, was of no avail. They were aware of this, the two officers said, but on the basis of the information they had about him, they would have to insist that he take the operation "desired by headquarters into his own hands."

Noch in derselben Nacht versammelte Lohse maßgebliche Kollegen um sich und beriet mit ihnen die Lage. Mit einer Reihe seiner engsten Mitarbeiter hatte er in den vorangegangenen Tagen schon wiederholt über die bevorstehende sowjetische Besetzung gesprochen, wobei sie sich einig gewesen waren, bis zur möglichen Liquidierung der Siemens-Betriebe durch die neue Besatzungsmacht auf jeden Fall in Thüringen zu bleiben. An diesem Entschluß änderte zunächst auch die amerikanische Aufforderung zur Übersiedlung in den Westen nichts, zumal sich in der nächtlichen Beratung zeigte, daß eine Reihe von Siemens-Mitarbeitern bereit waren, "mit ihren Familien dem Angebot der amerikanischen Regierung zu folgen". Andere leitende Angestellte dachten ebenso wie Lohse gar nicht daran, auf die Vorschläge der Besatzungsmacht einzugehen.

Als der Morgen des 22. Juni kam, mußte die Siemens-Spitze in Arnstadt feststellen, daß sie überhaupt keine Entscheidungsfreiheit besaß. Die Amerikaner lehnten die vorbereitete Liste von Ersatzleuten, die bereit waren, mit ihnen abzurücken und die besagte neue Fabrik im Westen aufzubauen, glatt ab. "Mr. Ernest nahm kaum Kenntnis von dieser Aufstellung", so beschreibt Direktor Lohse die Konfrontation mit der Besatzungsmacht, "sondern erklärte in ziemlich steifem Ton, daß er diese meine Stellungnahme erwartet habe nach der ganzen hinhaltenden Besprechung am Abend zuvor. Die Herren hätten inzwischen mit dem Hauptquartier telefonisch gesprochen und müßten mir nunmehr eröffnen, *daß von einer freiwilligen Abreise nicht die Rede sein könne*, sondern auch die Herren, die in Thüringen bleiben wollten, mit ihren Familien sich schnellstens zum Abtransport fertig zu machen hätten."[317] Lohse und die übrigen maßgeblichen Siemens-Mitarbeiter, hinter denen die Amerikaner her waren, erkannten jetzt, da weitere Debatten sinnlos waren.

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[317] Hervorhebung von mir.

That same night, Lohse gathered senior colleagues around him and discussed the situation with them. In the preceding days, he had repeatedly discussed the impending Soviet occupation with a number of his closest coworkers, and they had agreed to remain in Thuringia in any case until the possible liquidation of the Siemens plants by the new occupying power. Initially, the American request to relocate to the West did not change this decision, especially since it became apparent during the nighttime meeting that a number of Siemens employees were prepared to "follow the American government's offer with their families." Other senior executives, like Lohse, did not even think of responding to the occupation forces' proposals.

When the morning of 22 June came, the Siemens top management in Arnstadt had to realize that they had no freedom of decision at all. The Americans flatly rejected the prepared list of replacements who were willing to leave with them and build the new factory in question in the West. "Mr. Ernest hardly took any notice of this list," is how Director Lohse describes the confrontation with the occupation forces, "but explained in a rather stiff tone that he had expected this statement of mine after the whole stalling meeting the night before. In the meantime, the gentlemen had spoken to headquarters by telephone and would now have to inform me *that there could be no question of a voluntary departure*, but that the gentlemen who wanted to stay in Thuringia would have to get ready for departure with their families as soon as possible."[317] Lohse and the other key Siemens employees, whom the Americans were after, now realized that further debates were pointless.

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[317] Emphasis mine.

Am Morgen des Sonntag, dem 24. Juni, erfolgte der Abtransport der meisten der “befohlenen Herren” und ihrer Familien. Einigen mag es zur Beruhigung gedient haben, daß der unmittelbar vor der Evakuierung in Arnstadt auftauchende Werner von Siemens aus der Sicht der Konzernleitung keine prinzipiellen Bedenken gegen das amerikanische Vorhaben erhob. Dies genügte freilich nicht allen, um sich auf das Abenteuer der ungewissen Reise einzulassen. Ein leitender Angestellter, Wilhelm Vox, weigerte sich am Sontag noch immer mitzufahren. Daraufhin wurde er von der Besatzungsmacht verhaftet und gesondert abtransportiert. Wenige Tage später fand auch er sich in der US-Zone wieder.

Neben den leitenden Angestellten und deren Familien fuhren die Amerikaner aus dem Arnstadter Werk überdies 18 mit Maschinen und elektrotechnischen Geräten beladene Lastwagen über die Zonengrenze. Direktor Lohse und seinem engsten Mitarbeiter, die darauf bestanden, die Abwicklung auch in anderen Werken noch selbst zu überwachen, hatte die Besatzungsmacht das Recht eingeräumt, dem Haupttransport erst drei Tage später zu folgen. Als sie sich dann selbst nach Westen absetzten, sagten sie dem aufsichtsführenden amerikanischen Offizier unverhohlen ins Gesicht, daß sie “das feste Bewußtsein hätten, nicht eine Fabrik aufzubauen, wohl aber in ein Gefangenenlager zu kommen”.

On the morning of Sunday, 24 June, most of the “commanded gentlemen” and their families were transported away. Some may have been reassured by the fact that Werner von Siemens, who appeared in Arnstadt immediately before the evacuation, did not raise any objections in principle to the American plan from the point of view of the company management. This, of course, was not enough for everyone to embark on the adventure of the uncertain journey. One senior employee, Wilhelm Vox, still refused to go along on Sunday. As a result, he was arrested by the occupying forces and taken away separately. A few days later he too found himself in the U.S. zone.

In addition to the executives and their families, the Americans also drove 18 trucks loaded with machines and electrotechnical equipment from the Arnstadt plant across the zone border. Director Lohse and his closest colleague, who insisted on still supervising the processing in other plants themselves, had been granted the right by the occupying forces to follow the main transport only three days later. When they then set off westward themselves, they blatantly told the supervising American officer to his face that they “were firmly aware that they were not going to build a factory, but that they were going to a prison camp.”

Die Amerikaner haben nicht nur aus Arnstadt, sondern aus allen größeren Siemens-Werken Mitteldeutschlands Spitzenkräfte zwangsevakuiert, aus Rudolstadt ebenso wie aus Gera und aus Beendorf bei Helmstedt oder Molsdorf bei Erfurt.[318] Allein aus Gera und Arnstadt waren es einschließlich der Familienangehörigen ungefähr 125 Personen, darunter insgesamt gewiß mehrere Dutzend erstrangige Kräfte des Konzerns, denn Ende 1945 fanden sich noch immer über 30 von ihnen im Gewahrsam von FIAT; zwei Drittel kamen aus Arnstadt, wo sich die meisten Siemens-Angehörigen gesammelt hatten.[319]

The Americans forcibly evacuated top personnel not only from Arnstadt, but from all the larger Siemens plants in central Germany, from Rudolstadt as well as from Gera and from Beendorf near Helmstedt or Molsdorf near Erfurt.[318] From Gera and Arnstadt alone, there were about 125 people, including family members, among them certainly several dozen first-rate employees of the company, because at the end of 1945, more than 30 of them were still in FIAT custody; two thirds came from Arnstadt, where most Siemens employees had gathered.[319]

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[318] Die Evakuierungen an diesen Standorten sind verschiedentlich erwähnt, so in Lohses Schilderung selbst, aber auch bei Gimbel, U.S. Policy and German Scientists, S. 440, sowie in dem Bericht Marschall Schukows an Stalin von Ende Juni 1945 ("Marshall Zhukov's Report on Removal by the Allies of Equipment and other Property from the factories in the Soviet Zone of Occupation"), auf den weiter unten näher eingegangen wird; abgedruckt in: FRUS, Conference of Berlin, II, S. 906 ff.

[319] Vgl. neben dem Bericht von Direktor Lohse die von FIAT zusammengestellte Liste aus Mitteldeutschland evakuierter Wissenschaftler und Techniker v. 19. 12. 1945; NA, RG 243, European War, G-2 Library, Entry 36, Envelope 760. In dieser umfangreichen Aufstellung, die etwa die Hälfte der insgesamt zwangsevakuierten Experten aufführt, findet sich auch der Name von Dr. Wilhelm Vox, der sich zunächst geweigert hatte, Arnstadt mit den Amerikanern zu verlassen, und daraufhin von der Besatzungsmacht verhaftet worden war.

[318] Evacuations at these sites are mentioned variously, as in Lohse's account itself, but also in Gimbel, U.S. Policy and German Scientists, p. 440, and in Marshal Zhukov's report to Stalin of late June 1945 ("Marshal Zhukov's Report on Removal by the Allies of Equipment and other Property from the factories in the Soviet Zone of Occupation"), discussed in more detail below; reprinted in: FRUS, Conference of Berlin, II, pp. 906 ff.

[319] See, in addition to the report by Director Lohse, the list of scientists and technicians evacuated from central Germany compiled by FIAT, dated December 19, 1945; NARA, RG 243, European War, G-2 Library, Entry 36, Box 760. This extensive list, which lists about half of the total number of forcibly evacuated experts, also includes the name of Dr. Wilhelm Vox, who had initially refused to leave Arnstadt with the Americans and was subsequently arrested by the occupying forces.

Die Zwangsevakuierten von Siemens wurden in das württembergische Heidenheim an der Brenz gebracht. Hier kamen sie zunächst in ein stark bewachtes, mit einem Drahtverhau umgebenes Barackenlager. Bald konnten sie in ein Schulhaus umziehen, und nach und nach wurden sie gewahr, daß sie ihr Schicksal mit Hunderten anderer "Internierter"—so Direktor Lohse—aus Thüringen teilten: "Die wahre Ursache des Transports nach Heidenheim konnte sehr schnell übersehen werden", berichtete er im November 1945 seiner Firma. "Offensichtlich hatte die amerikanische Regierung Wert darauf gelegt, alle Kräfte, die evtl. für den Wiederaufbau bzw. die Fertigungsfortsetzung von V-Waffen nützlich sein könnten, außerhalb Thüringens zu konzentrieren ... Die örtlichen militärischen Stellen der Amerikaner waren jedoch über die Absichten nicht im geringsten im Bilde. Sie hatten, wie mir ein amerikanischer Offizier selbst mitteilte, lediglich den Befehl vom Hauptquartier, as Thüringen verbrachte deutsche Fachkräfte unbedingt und sicher festzuhalten." Von einer "Unzahl von englischen und amerikanischen Militärkommissionen sämtlicher Truppenteile" wurden die Internierten ausgefragt, berichtete Lohse, aber keiner der Offiziere "konnte jemals auf unsere Frage antworten, ob und wann wir aus unserer Internierung entlassen würden". Auch die Bemühungen um Freilassung, die sofort von der Siemens-Gruppenleitung in München eingeleitet wurden, blieben zunächst ohne Erfolg. Erst Anfang Dezember konnten ungefähr zwei Drittel der in Heidenheim festgehaltenen Firmenmitglieder an den Erlanger Konzernstandort übersiedeln. Sie hatten sich weiterhin als interniert zu betrachten, konnten sich aber nun frei in der US-Zone bewegen. Verlassen durften sie das amerikanische Besatzungsgebiet nicht, wofür Direktor Lohse der Militärregierung persönlich zu bürgen hatte.

The forced evacuees from Siemens were taken to Heidenheim an der Brenz in Württemberg. Here they were initially placed in a heavily guarded barracks camp surrounded by a wire enclosure. Soon they were able to move into a schoolhouse, and gradually they became aware that they shared their fate with hundreds of other "internees"—as Director Lohse said—from Thuringia: "The true cause of the transport to Heidenheim could very quickly be overlooked," he reported to his company in November 1945. "Obviously, the American government had attached importance to concentrating outside Thuringia all forces that might be useful for the reconstruction or continuation of the production of V-weapons.... The local American military authorities, however, were not in the least aware of the intentions. They had, as an American officer himself told me, only the order from headquarters to hold German specialists deported to Thuringia absolutely and securely." Internees were questioned by a "number of English and American military commissions of all troop units," Lohse reported, but none of the officers "was ever able to answer our question as to whether and when we would be released from our internment." Efforts to secure release, which were immediately initiated by Siemens Group management in Munich, were also initially unsuccessful. It was not until early December that about two-thirds of the company members held in Heidenheim were able to move to the Erlangen group location. They still had to consider themselves interned, but could now move freely within the U.S. zone. They were not allowed to leave the American occupation zone, for which Director Lohse had to personally vouch to the military government.

Die Labors und Betriebsstätten der Telefunken, Gesellschaft für drahtlose Telegraphie m.b.H., die ebenfalls Bauteile für die V-Waffenproduktion entwickelt und hergestellt hatte, fanden bei den Amerikanern ähnliche Aufmerksamkeit wie die Fabriken des Konkurrenzunternehmens Siemens. Bereits am 16. Juni transportierte die Army (deren Ordnance Teams ja schon seit Ende Mai die Genehmigung hatten, Experten, die in irgendeiner Weise mit dem deutschen Raketetenprogramm verbunden waren, nach Westdeutschland zu bringen) aus der Fertigungsstätte in Bad Liebenstein im thüringischen Landkreis Meiningen den Konstrukteur Professor Fritz Schröter mit Frau und Tochter ab, nach dem sicheren Eindruck des Unternehmens eine Aktion "rein militärischen Charakters"[320]. Neben der Wegführung des prominenten Betriebsstättenleiters gab es auch freiwillige Abwanderungen mehrerer wichtiger Mitarbeiter und ihrer Familien, da die Firmenleitung—vermutlich unter dem Eindruck der bevorstehenden sowjetischen Besetzung—beschlossen hatte, ire während des Krieges nach Mitteldeutschland ausgelagerten Betriebe zurückzuführen. Als ester Sammelpunkt war Göttingen bestimmt worden, wohin deshalb im Laufe des Juni neben den Betriebsangchörigen auch Apparate, Geräte und Konstruktionsunterlagen gebracht wurden. In einer Aufstellung der Wirtschaftskammer Meiningen war sorgsam unterschieden zwischen denjenigen, die "abtransportiert" worden waren, und denen, die den Ort "freiwillig verlassen" hatten oder "unbekannt verzogen" waren. Einige der Abtransportierten—so Professor Hans Rukop (Röhrenexperte), Professor Paul Günther (Radarfachmann), Graf Michael von der Schulenburg oder Erich Chytrek, der auf dem Felde der Quarzkristalle forschte—befanden sich noch Ende des Jahres im Gewahrsam der alliierten Field Intelligence Agency, Technical. Aus dem Telefunken-Labor in Bad Blankenburg bei Rudolstadt hatte die Army bei ihrem Abzug neben wertvollen Apparaturen zwanzig Experten auf dem Gebiet der Funktechnik fortgeschafft.[321] Der Bestimmungsort der meisten Telefunken-Koryphäen war wie der ihrer Siemens-Kollegen das württembergische Städtchen Heidenheim.

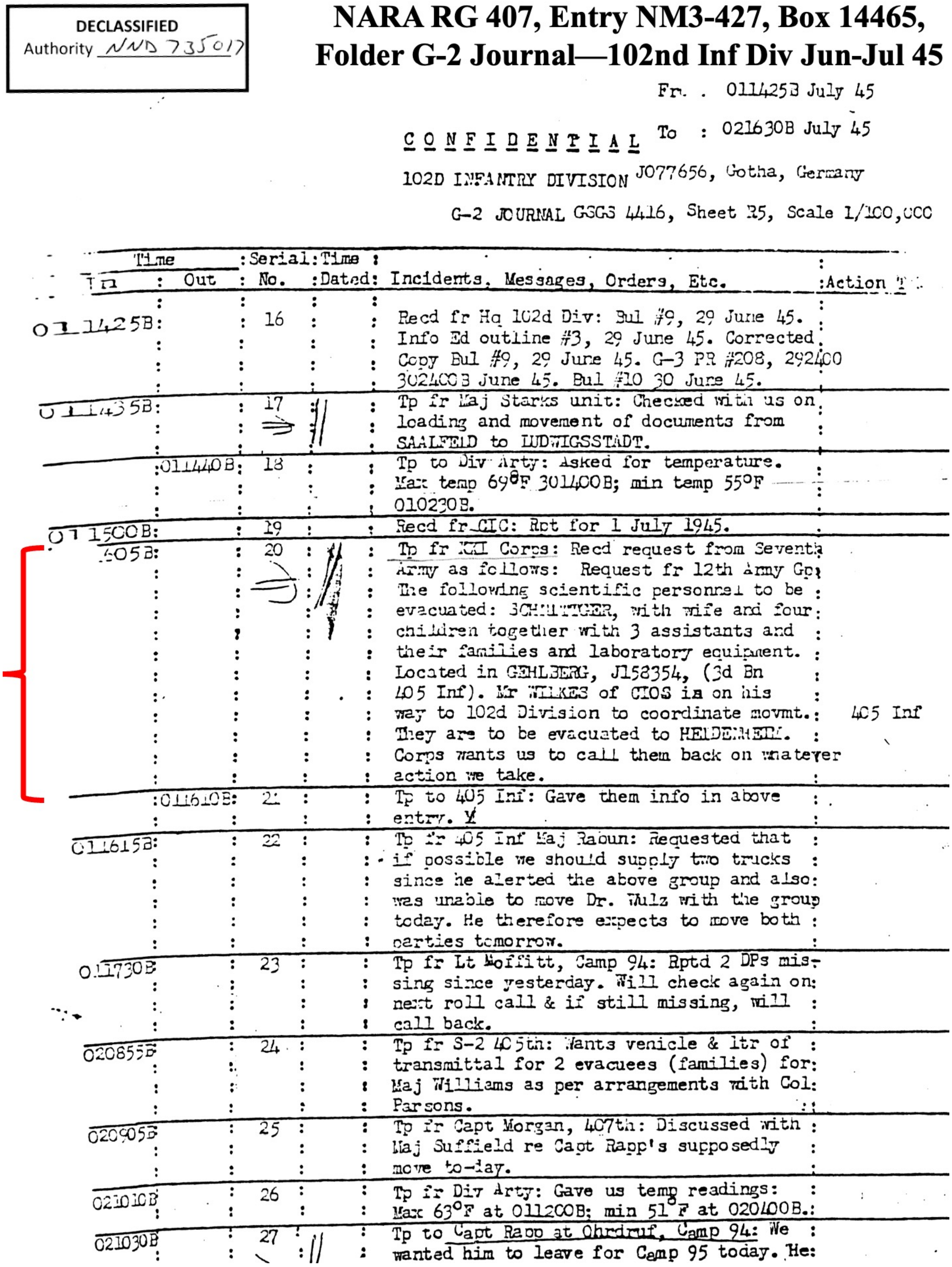
The laboratories and operating facilities of Telefunken, Gesellschaft für drahtlose Telegraphie m.b.H., which had also developed and manufactured components for V-weapon production, attracted similar attention from the Americans as the factories of the rival company Siemens. As early as 16 June, the Army (whose Ordnance Teams had already been authorized since the end of May to bring experts in any way connected with the German missile program to West Germany) transported the designer Professor Fritz Schröter with his wife and daughter from the manufacturing plant in Bad Liebenstein in the Thuringian district of Meiningen, according to the company's clear impression an action of "purely military character."[320] In addition to the departure of the prominent plant manager, there were also voluntary departures of several important employees and their families, since the company management—presumably under the impression of the impending Soviet occupation—had decided to return their operations that had been outsourced to central Germany during the war. Göttingen had been designated as the main assembly point, to which not only the employees but also apparatus, equipment, and design documents were brought in the course of June. In a list compiled by the Meiningen Chamber of Commerce, a careful distinction was made between those who had been "deported" and those who had "voluntarily left" the town or had "moved to an unknown address." Some of the deportees—such as Professor Hans Rukop (tube expert), Professor Paul Günther (radar expert), Count Michael von der Schulenburg, or Erich Chytrek, who was doing research in the field of quartz crystals—were still in the custody of the Allied Field Intelligence Agency, Technical at the end of the year. When the Army withdrew from the Telefunken laboratory in Bad Blankenburg near Rudolstadt, it had taken away twenty experts in the field of radio technology as well as valuable equipment.[321] The destination of most of the Telefunken luminaries, like that of their Siemens colleagues, was the small town of Heidenheim in Württemberg.

[320] Schreiben der Telefunkenbetriebsstätte Bad Liebenstein an den örtlichen Bürgermeister v. 30. 7. 1945. Dokument Nr. 37 im Anhang zu Fuchs, Besatzungspolitik der USA; vgl. auch ebenda, S. 139. Siehe auch Dokument Nr. 38, "Feststeilung der von amerikanischen Besatzungsbehörden mitgeführten Vermögenswerte, Patente, Personen usw." der Geschäftsstelle Meiningen der Wirtschaftskammer Thüringen, ohne Datum, Stichtag 15. 7. 1943. Die genannten Namen finden sich auf der oben erwähnten FIAT-Liste: NA, RG 243. European War, G-2 Library, Entry 36, Envelope 760.

[321] Schukow-Bericht an Stalin; abgedruckt in FRUS, Conference of Berlin II, S. 909.

[320] Letter from Telefunken Betriebsstätte Bad Liebenstein to the local mayor v. 30. 7. 1945. Document No. 37 in the appendix to Fuchs, Besatzungspolitik der USA; cf. also ibid. p. 139. See also Document No. 38, "Festteilung der von amerikanischen Besatzungsbehörden mitgeführten Vermögenswerte, Patente, Personen usw." der Geschäftsstelle Meiningen der Wirtschaftskammer Thüringen, ohne Datum, Stichtag 15. 7. 1943. The names mentioned can be found on the FIAT list mentioned above: NARA, RG 243. European War, G-2 Library, Entry 36, Box 760.

[321] Zhukov report to Stalin; reprinted in FRUS, Conference of Berlin II, p. 909.



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C O N F I D E N T I A L

102D INFANTRY DIVISION J077656, Gotha, Germany

G-2 JOURNAL GSGS 4416, Sheet R5, Scale 1/100,000

Time In	Time Out	Serial No.	Time Dated	Incidents, Messages, Orders, Etc.	Action T
011425B		16		Recd fr Hq 102d Div: Bul #9, 29 June 45. Info Ed outline #3, 29 June 45. Corrected Copy Bul #9, 29 June 45. G-3 PR #208, 292400 302400B June 45. Bul #10 30 June 45.	
011435B		17		Tp fr Maj Starks unit: Checked with us on loading and movement of documents from SAALFELD to LUDWIGSSTADT.	
	011440B	18		Tp to Div Arty: Asked for temperature. Max temp 69°F 301400B; min temp 55°F 010230B.	
011500B		19		Recd fr CIC: Rpt for 1 July 1945.	
605B		20		Tp fr XXI Corps: Recd request from Seventh Army as follows: Request fr 12th Army Gp; The following scientific personnel to be evacuated: SCHNITTGER, with wife and four children together with 3 assistants and their families and laboratory equipment. Located in GEHLBERG, J158354, (3d Bn 405 Inf). Mr WILKES of CIOS is on his way to 102d Division to coordinate movmt. They are to be evacuated to HEIDENHEIM. Corps wants us to call them back on whatever action we take.	405 Inf
	011610B	21		Tp to 405 Inf: Gave them info in above entry.	
011615B		22		Tp fr 405 Inf Maj Raboun: Requested that if possible we should supply two trucks since he alerted the above group and also was unable to move Dr. Wulz with the group today. He therefore expects to move both parties tomorrow.	
011730B		23		Tp fr Lt Moffitt, Camp 94: Rptd 2 DPs missing since yesterday. Will check again on next roll call & if still missing, will call back.	
020855B		24		Tp fr S-2 405th: Wants vehicle & ltr of transmittal for 2 evacuees (families) for Maj Williams as per arrangements with Col. Parsons.	
020905B		25		Tp fr Capt Morgan, 407th: Discussed with Maj Suffield re Capt Rapp's supposedly move to-day.	
021010B		26		Tp fr Div Arty: Gave us temp readings: Max 63°F at 011200B; min 51°F at 020400B.	
021030B		27		Tp to Capt Rapp at Ohrdruf, Camp 94: We wanted him to leave for Camp 95 today. He:	

Figure B.255: In summer 1945, the United States “evacuated” German scientists who developed traveling wave tubes for the “master standard transmitter” radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber, as well as their equipment and information [NARA RG 407, Entry NM3-427, Box 14465, Folder G-2 Journal—102nd Inf Div Jun–Jul 45]. See also p. 1221 and Section E.2.

NARA RG 238, Entry NM70-160, Box 30,
Folder FIAT—Misc.—Reports—No. 1–10

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SECRET
- 28 -

A.	B.	C. From.	C. To.
HORLACHER Paul	Asst. to Dr. HELFERICH	LEIPZIG	ARNSDORF
HORN Dr. Erhard	Rocket Expert, with Dr. Theodor HORN. Gyro control and steering devices.. Drawings and test reports also evacuated.	PLAUEN	HEIDENHEIM
HORNAUER Helmut	Engineer	DELITSCH	FRIEDBERG
HOSS Otto	Engineer	BERNBURG	DARMSTADT
HOTSEL Dr. Johannes	Pharmazenhisch - Chemisches Inst. Labotarory equipment. Refractometers. spectrum photometers also evacuated.	ILMENAU	HEIDENHEIM
HUBER Dr. Dir.	Kieselchemie. GmbH	KAMMACHMÜHLE	HEIDENHEIM
HOF Dr. Arnst	Asst. Pharm. Inst.	LEIPZIG	ARNSDORF
HUFENREUTER Karl	Betriebsfuhrer Braunkohlenbergbau Deutsche Solvay Werke A.G.	OSTERNIENBURG	DARMSTADT
HULLNECK Dr. Gustav	Chemist	BERNBURG	DARMSTADT
HUNMARCK		GEHLBERG	HEIDENHEIM
HÜPPE Günther	Mechanical Foreman. Physikalisches. Inst. DANZIG. Forschungsstelle für Metalle	SCHMALKALDEN	HEIDENHEIN
HUPPERTS Josef	Assessor	BERNBURG	HEIDENHEIM
ILSE Heinrich		JENA	HEIDENHEIM
ILLNER Gotthold	Asst. Chemist	LEIPZIG	ARNSDORF
IMIG Dr. Helmut	Chemist I.G. FARBEN	LEIPZIG	ARNSDORF
JACOBS N.B.		SCHKOPAU	ROSENTHAL

SECRET
- 42 -

A.	B.	C. From	C. To
LOHMANN Erich	Pittler Werke	LEIPZIG	WEILBURG
LOHMANN Hermann	Deutsche Solvay Werke A.G.	BERNBURG	DARMSTADT
LOHSE Dr. Adolf	Director. Siemens and Halske. (Master standard transmitters - radio- measuring and testing instruments also evacuated)	ARNSTADT	HEIDENHEIM
LOMMATZSCH Werner		LEIPZIG	ARNSDORF
LONG Dr.	Research Chemist I.G. FARBEN	BITTERFELD	DARMSTADT
LORENZ Prof. Dr. Rudolf	Landwirtsch. Hochschule. Akademie für Technik. Chemistry.	KOTHEN	DARMSTADT
VON LÖSSL Prof. Dr. Ernst	Staatl Akademie für Technik. KOTHEN. Aero-design and high velocity technique. Chief of the Flugtechnisches Inst.	KOTHEN	DARMSTADT
LOTH Dr.	Lawyer	MEININGEN	HEIDENHEIM
LUCE Dir.	Production Expert. Rheinmetall Borsig	SOMMERDA	DILLENBURG
LUCHS Ob, Ing. Fritz	Technician.	SOMMERDA	DILLENBURG
LÜCKERT Karl	Schott and Genossen	JENA	HEIDENHEIM
LUDECKE Prof. Hans		BERNBURG	DARMSTADT
LUDWIG Georg	Engineer	BERNBURG	DARMSTADT
LUDWIG Ob. Ing.	Rheinmetall Borsig	MUHLHAUSEN	DILLENBURG
LUEDERS Peter Jergen	Siemens and Halske	ARNSTADT	HEIDENHEIM
LUGE Max		LEIPZIG	WEILBURG

Figure B.256: In summer 1945, the United States "evacuated" German scientists who developed traveling wave tubes for the "master standard transmitter" radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber, as well as their equipment and information [NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10]. See also p. 1221 and Section E.2.

NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10

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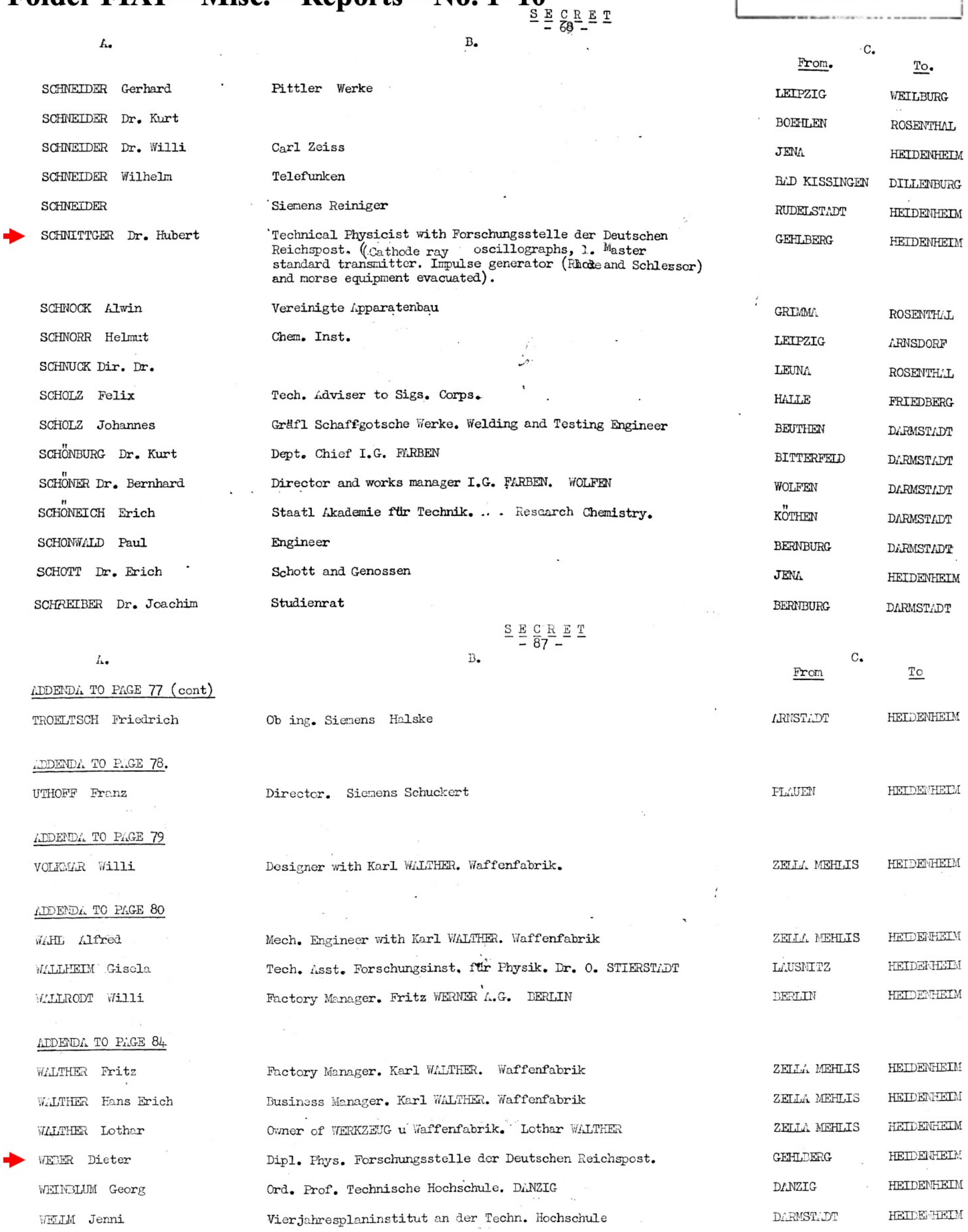

S E C R E T
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A.	B.	C.	
		From.	To.
SCHNEIDER Gerhard	Pittler Werke	LEIPZIG	WEILBURG
SCHNEIDER Dr. Kurt		BOEHLEN	ROSENTHAL
SCHNEIDER Dr. Willi	Carl Zeiss	JENA	HEIDENHEIM
SCHNEIDER Wilhelm	Telefunken	BAD KISSINGEN	DILLENBURG
SCHNEIDER	Siemens Reiniger	RUDELSTADT	HEIDENHEIM
➡ SCHNITTGER Dr. Hubert	Technical Physicist with Forschungsstelle der Deutschen Reichspost. ((Cathode ray oscillographs, 1. Master standard transmitter. Impulse generator (Rhode and Schlessor) and morse equipment evacuated).	GEHLBERG	HEIDENHEIM
SCHNOCK Alwin	Vereinigte Apparatenbau	GRIMMA	ROSENTHAL
SCHNORR Helmut	Chem. Inst.	LEIPZIG	ARNSDORF
SCHNUCK Dir. Dr.		LEUNA	ROSENTHAL
SCHOLZ Felix	Tech. Adviser to Sigs. Corps.	HALLE	FRIEDBERG
SCHOLZ Johannes	Gräfl Schaffgotsche Werke. Welding and Testing Engineer	BEUTHEN	DARMSTADT
SCHÖNBURG Dr. Kurt	Dept. Chief I.G. FARBEN	BITTERFELD	DARMSTADT
SCHÖNER Dr. Bernhard	Director and works manager I.G. FARBEN. WOLFEN	WOLFEN	DARMSTADT
SCHÖNEICH Erich	Staatl Akademie für Technik. .. . Research Chemistry.	KÖTHEN	DARMSTADT
SCHONWALD Paul	Engineer	BERNBURG	DARMSTADT
SCHOTT Dr. Erich	Schott and Genossen	JENA	HEIDENHEIM
SCHREIBER Dr. Joachim	Studienrat	BERNBURG	DARMSTADT

S E C R E T
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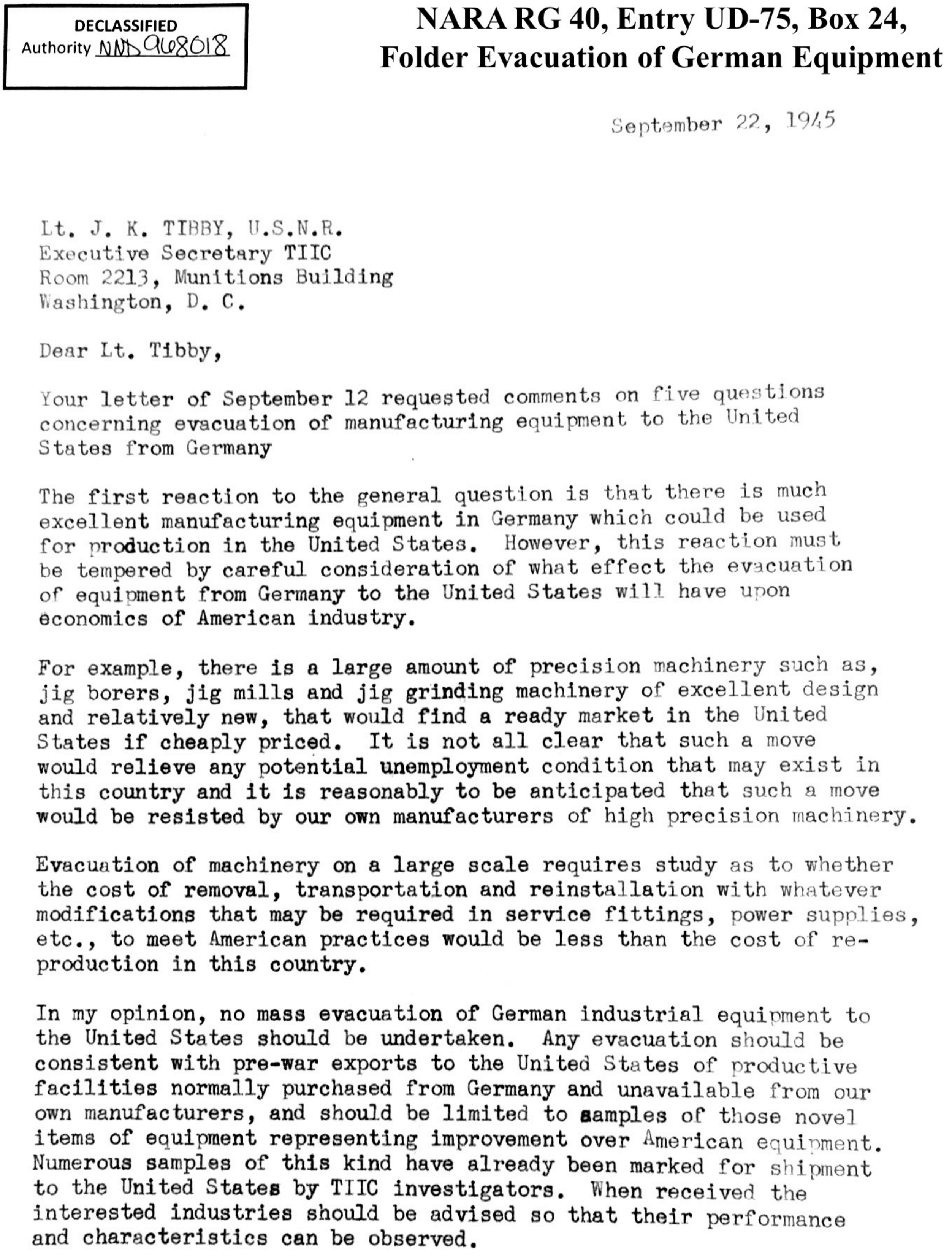
A.	B.	C.	
		From	To
ADDENDA TO PAGE 77 (cont)			
TROELTSCH Friedrich	Ob ing. Siemens Halske	ARNSTADT	HEIDENHEIM
ADDENDA TO PAGE 78.			
UTHOFF Franz	Director. Siemens Schuckert	PLAUEN	HEIDENHEIM
ADDENDA TO PAGE 79			
VOLKMAR Willi	Designer with Karl WALTHER. Waffenfabrik.	ZELLA MEHLIS	HEIDENHEIM
ADDENDA TO PAGE 80			
WAHL Alfred	Mech. Engineer with Karl WALTHER. Waffenfabrik	ZELLA MEHLIS	HEIDENHEIM
WALLHEIM Gisela	Tech. Asst. Forschungsinst. für Physik. Dr. O. STIERSTADT	LAUSNITZ	HEIDENHEIM
WALLRODT Willi	Factory Manager. Fritz WERNER A.G. BERLIN	BERLIN	HEIDENHEIM
ADDENDA TO PAGE 84			
WALTHER Fritz	Factory Manager. Karl WALTHER. Waffenfabrik	ZELLA MEHLIS	HEIDENHEIM
WALTHER Hans Erich	Business Manager. Karl WALTHER. Waffenfabrik	ZELLA MEHLIS	HEIDENHEIM
WALTHER Lothar	Owner of WERKZEUG u Waffenfabrik. Lothar WALTHER	ZELLA MEHLIS	HEIDENHEIM
➡ WEBER Dieter	Dipl. Phys. Forschungsstelle der Deutschen Reichspost.	GEHLBERG	HEIDENHEIM
WEINBLUM Georg	Ord. Prof. Technische Hochschule. DANZIG	DANZIG	HEIDENHEIM
WELIM Jenni	Vierjahresplaninstitut an der Techn. Hochschule	DARMSTADT	HEIDENHEIM

Figure B.257: In summer 1945, the United States “evacuated” German scientists who developed traveling wave tubes for the “master standard transmitter” radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber, as well as their equipment and information [NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10]. See also p. 1221 and Section E.2.



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NARA RG 40, Entry UD-75, Box 24,
Folder Evacuation of German Equipment

September 22, 1945

Lt. J. K. TIBBY, U.S.N.R.
Executive Secretary TIIC
Room 2213, Munitions Building
Washington, D. C.

Dear Lt. Tibby,

Your letter of September 12 requested comments on five questions concerning evacuation of manufacturing equipment to the United States from Germany

The first reaction to the general question is that there is much excellent manufacturing equipment in Germany which could be used for production in the United States. However, this reaction must be tempered by careful consideration of what effect the evacuation of equipment from Germany to the United States will have upon economics of American industry.

For example, there is a large amount of precision machinery such as, jig borers, jig mills and jig grinding machinery of excellent design and relatively new, that would find a ready market in the United States if cheaply priced. It is not all clear that such a move would relieve any potential unemployment condition that may exist in this country and it is reasonably to be anticipated that such a move would be resisted by our own manufacturers of high precision machinery.

Evacuation of machinery on a large scale requires study as to whether the cost of removal, transportation and reinstallation with whatever modifications that may be required in service fittings, power supplies, etc., to meet American practices would be less than the cost of reproduction in this country.

In my opinion, no mass evacuation of German industrial equipment to the United States should be undertaken. Any evacuation should be consistent with pre-war exports to the United States of productive facilities normally purchased from Germany and unavailable from our own manufacturers, and should be limited to samples of those novel items of equipment representing improvement over American equipment. Numerous samples of this kind have already been marked for shipment to the United States by TIIC investigators. When received the interested industries should be advised so that their performance and characteristics can be observed.

Figure B.258: In summer 1945, the U.S. military and AT&T "evacuated" German scientists who developed traveling wave tubes for the "master standard transmitter" radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber (plus many other electronics experts), as well as their equipment and information [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment]. See also p. 1221 and Section E.2.

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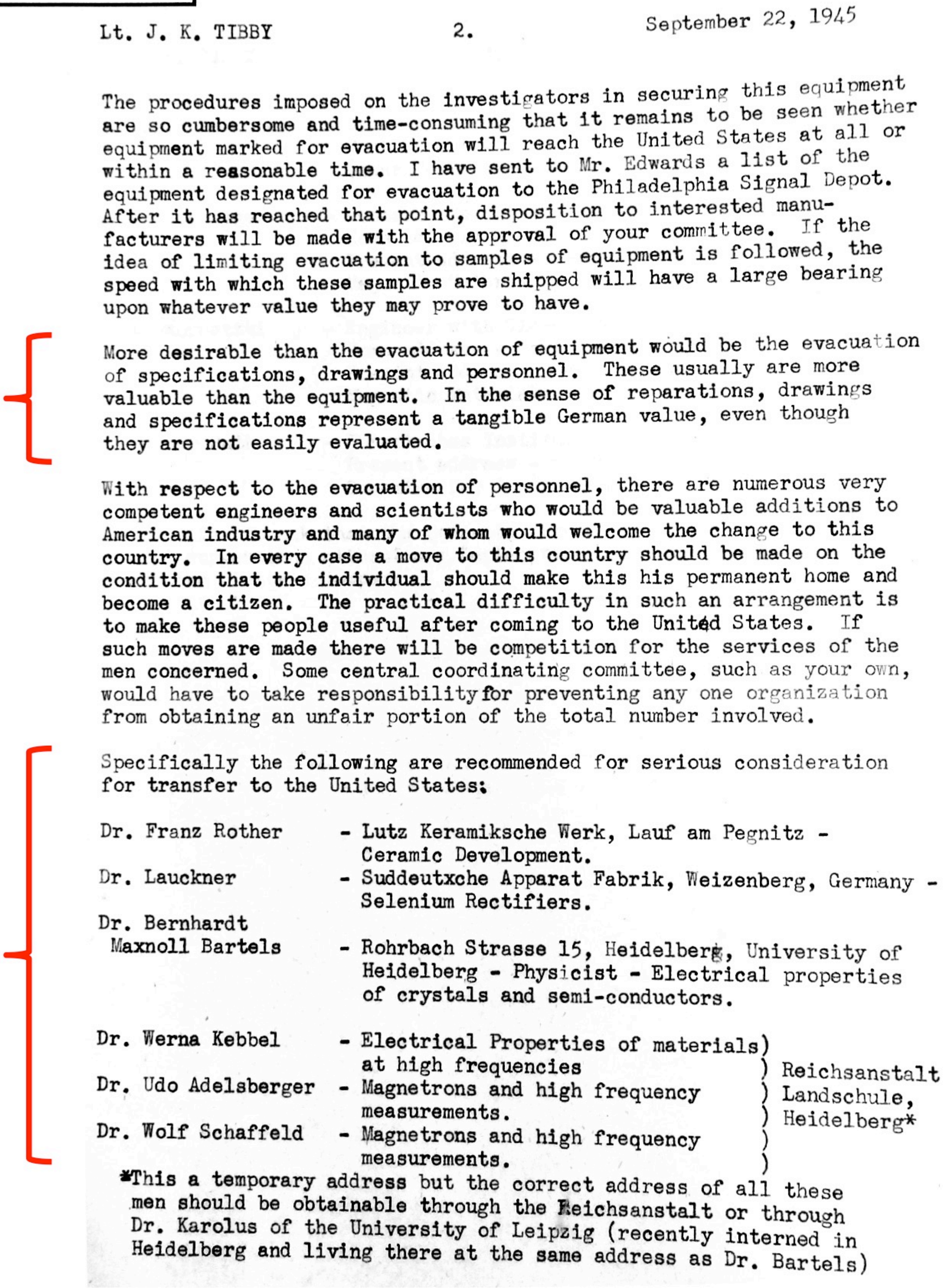
NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment



Lt. J. K. TIBBY 2. September 22, 1945

The procedures imposed on the investigators in securing this equipment are so cumbersome and time-consuming that it remains to be seen whether equipment marked for evacuation will reach the United States at all or within a reasonable time. I have sent to Mr. Edwards a list of the equipment designated for evacuation to the Philadelphia Signal Depot. After it has reached that point, disposition to interested manufacturers will be made with the approval of your committee. If the idea of limiting evacuation to samples of equipment is followed, the speed with which these samples are shipped will have a large bearing upon whatever value they may prove to have.

More desirable than the evacuation of equipment would be the evacuation of specifications, drawings and personnel. These usually are more valuable than the equipment. In the sense of reparations, drawings and specifications represent a tangible German value, even though they are not easily evaluated.

With respect to the evacuation of personnel, there are numerous very competent engineers and scientists who would be valuable additions to American industry and many of whom would welcome the change to this country. In every case a move to this country should be made on the condition that the individual should make this his permanent home and become a citizen. The practical difficulty in such an arrangement is to make these people useful after coming to the United States. If such moves are made there will be competition for the services of the men concerned. Some central coordinating committee, such as your own, would have to take responsibility for preventing any one organization from obtaining an unfair portion of the total number involved.

Specifically the following are recommended for serious consideration for transfer to the United States:

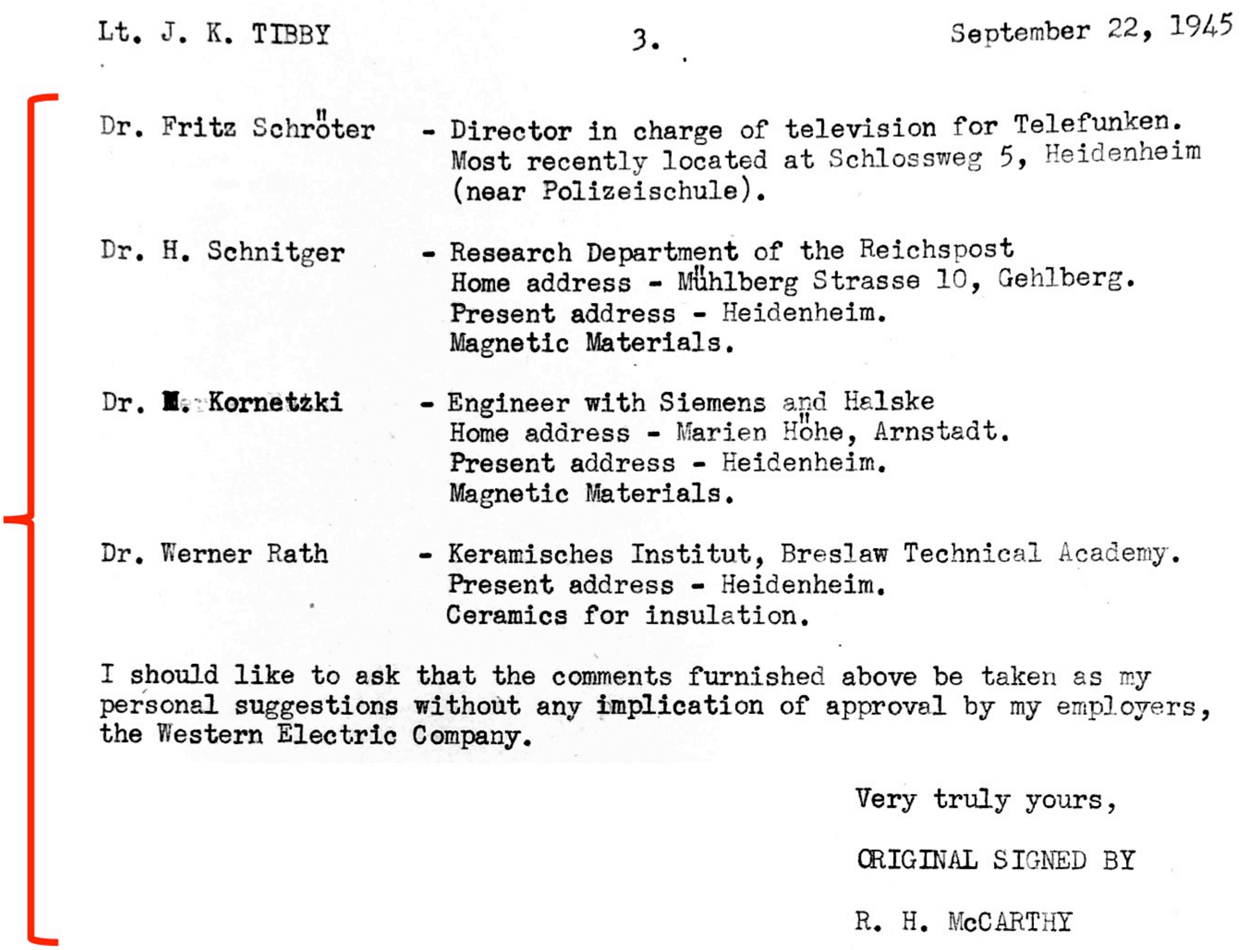
Dr. Franz Rother	- Lutz Keramiksche Werk, Lauf am Pegnitz - Ceramic Development.	
Dr. Lauckner	- Suddeutxche Apparat Fabrik, Weizenberg, Germany - Selenium Rectifiers.	
Dr. Bernhardt Maxnoll Bartels	- Rohrbach Strasse 15, Heidelberg, University of Heidelberg - Physicist - Electrical properties of crystals and semi-conductors.	
Dr. Werna Kebbel	- Electrical Properties of materials at high frequencies	Reichsanstalt Landschule, Heidelberg*
Dr. Udo Adelsberger	- Magnetrons and high frequency measurements.	
Dr. Wolf Schaffeld	- Magnetrons and high frequency measurements.	

*This a temporary address but the correct address of all these men should be obtainable through the Reichsanstalt or through Dr. Karolus of the University of Leipzig (recently interned in Heidelberg and living there at the same address as Dr. Bartels)

Figure B.259: In summer 1945, the U.S. military and AT&T "evacuated" German scientists who developed traveling wave tubes for the "master standard transmitter" radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber (plus many other electronics experts), as well as their equipment and information [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment]. See also p. 1221 and Section E.2.

DECLASSIFIED
Authority NND 968018

NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment



Lt. J. K. TIBBY 3. September 22, 1945

Dr. Fritz Schröter	- Director in charge of television for Telefunken. Most recently located at Schlossweg 5, Heidenheim (near Polizeischule).
Dr. H. Schnitger	- Research Department of the Reichspost Home address - Mühlberg Strasse 10, Gehlberg. Present address - Heidenheim. Magnetic Materials.
Dr. M. Kornetzki	- Engineer with Siemens and Halske Home address - Marien Höhe, Arnstadt. Present address - Heidenheim. Magnetic Materials.
Dr. Werner Rath	- Keramisches Institut, Breslaw Technical Academy. Present address - Heidenheim. Ceramics for insulation.

I should like to ask that the comments furnished above be taken as my personal suggestions without any implication of approval by my employers, the Western Electric Company.

Very truly yours,

ORIGINAL SIGNED BY

R. H. McCARTHY

Figure B.260: In summer 1945, the U.S. military and AT&T "evacuated" German scientists who developed traveling wave tubes for the "master standard transmitter" radio-inertial guidance system on rockets, including Erhard Horn, Adolf Lohse, Herbert Schnitger, and Dieter Weber (plus many other electronics experts), as well as their equipment and information [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment]. See also p. 1221 and Section E.2.

NEW TUBE EXPANDS RADIO POSSIBILITIES

Device Can Send 10,000 Phone Calls at Once, 100 Million Wired Words a Minute

WIDENS TELEVISION FIELD

Old Broadcast Band Enlarged 800 Times and Improves Service in Accordance

By T. R. KENNEDY Jr.

A novel vacuum tube, not much larger than an ordinary radio receiving bulb, was made public here yesterday. It is expected to do as much for the future of very-high-frequency nation-wide communication as the deForest "audion" did for the broadcast and world-wide telephony and telegraphy pioneers a quarter of a century or more ago.

A product of the Bell Telephone Laboratories, the new device is said to make possible a "wave-guide" network of coast-to-coast proportions over which 10,000 telephone conversations may go simultaneously, or all the television programs needed for all the video stations likely to be operating in this country in years to come.

A wave-guide is a hollow metal tube through which "radio" waves may move like water. Wave-guides came into their own during the war, when no high-power radar could get along without them. The principle now is being applied to communication purposes.

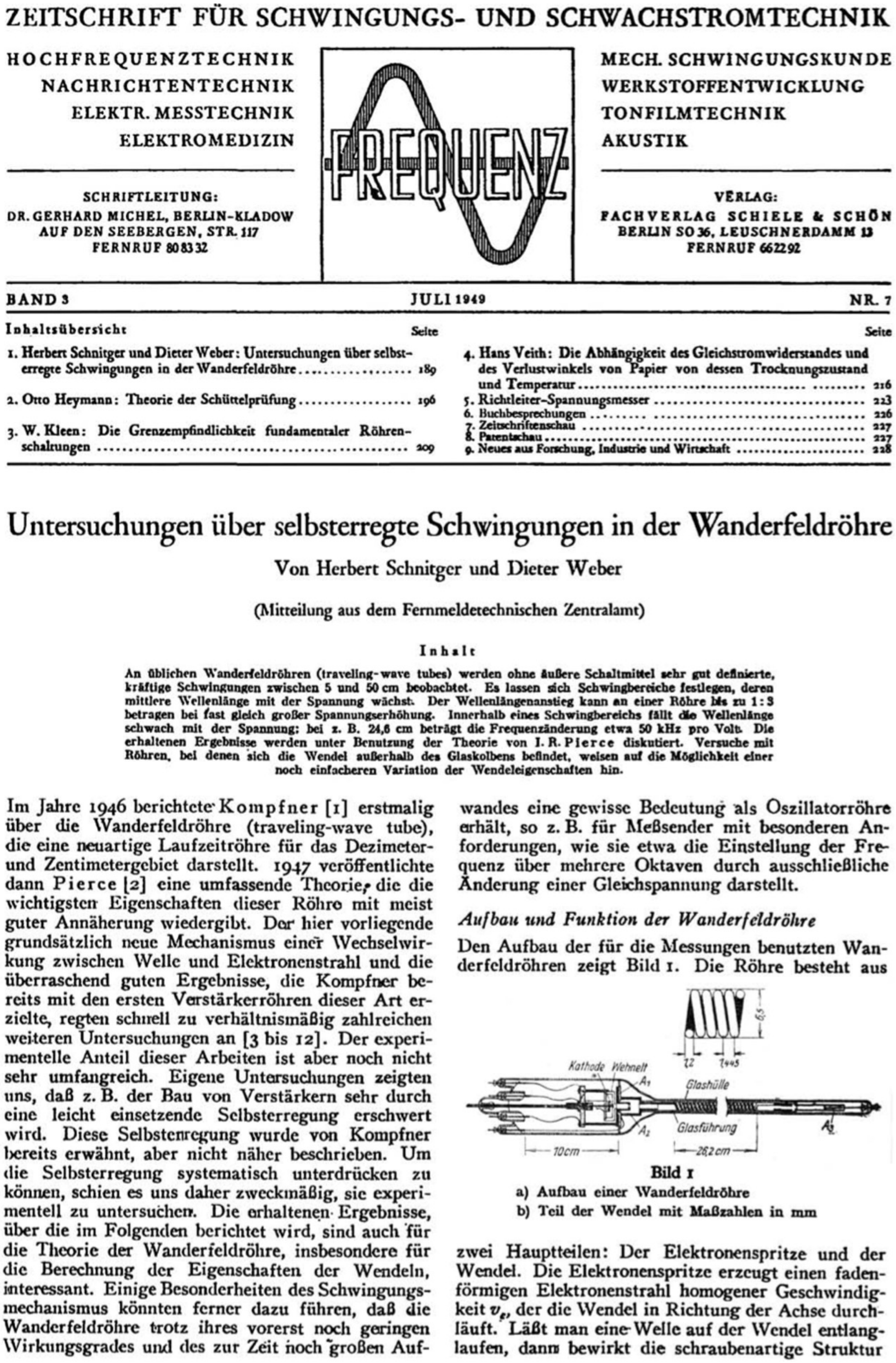
Far Reaching in Significance

So far-reaching and significant are the new horizons thus created that experts hesitate to predict the full possibilities of such a network, which now seem to be appreciably nearer by the development of the new tube, technically known as a "traveling-wave" tube.

For instance, a wave-guide system set up to transmit and receive dots and dashes of the Morse code instead of telephone speech or television images would carry easily the equivalent of one hundred million words in dots and dashes each minute, it was said. An ordinary radio channel on the average world-wide frequencies carries only a few hundreds of words a minute.

The new tube has been expanded in other ways besides that of channel width. In the laboratory it has been able to "amplify" a signal millions of cycles wide so effectively as to produce what engineers call "a power gain of 10,000 times." When doing this, the tube operates over a band 800 megacycles wide (800 times as wide as the whole broadcast band from WQXR to above WMCA on the dial), and does it "1,000 times better" than the best other tubes of conventional design.

Figure B.261: One year later, in summer 1946, AT&T publicly claimed that it had just invented the traveling wave tube, which would revolutionize communications [NYT 1946-07-06].



ZEITSCHRIFT FÜR SCHWINGUNGS- UND SCHWACHSTROMTECHNIK

HOCHFREQUENZTECHNIK
NACHRICHTENTECHNIK
ELEKTR. MESSTECHNIK
ELEKTROMEDIZIN

FREQUENZ

MECH. SCHWINGUNGSKUNDE
WERKSTOFFENTWICKLUNG
TONFILMTECHNIK
AKUSTIK

SCHRIFTLEITUNG:
DR. GERHARD MICHEL, BERLIN-KLADOW
AUF DEN SEEBERGEN, STR. 117
FERNRUF 808332

VERLAG:
FACHVERLAG SCHIELE & SCHÖN
BERLIN SO 36, LEUSCHNERDAMM 13
FERNRUF 662292

BAND 3 JULI 1949 NR. 7

Inhaltsübersicht

Untersuchungen über selbsterregte Schwingungen in der Wanderfeldröhre

Von Herbert Schnitger und Dieter Weber

(Mitteilung aus dem Fernmeldetechnischen Zentralamt)

Inhalt

An üblichen Wanderfeldröhren (traveling-wave tubes) werden ohne äußere Schaltmittel sehr gut definierte, kräftige Schwingungen zwischen 5 und 50 cm beobachtet. Es lassen sich Schwingbereiche festlegen, deren mittlere Wellenlänge mit der Spannung wächst. Der Wellenlängenanstieg kann an einer Röhre bis zu 1:3 betragen bei fast gleich großer Spannungserhöhung. Innerhalb eines Schwingbereichs fällt die Wellenlänge schwach mit der Spannung; bei z. B. 24,6 cm beträgt die Frequenzänderung etwa 50 kHz pro Volt. Die erhaltenen Ergebnisse werden unter Benutzung der Theorie von I. R. Pierce diskutiert. Versuche mit Röhren, bei denen sich die Wendel außerhalb des Glaskolbens befindet, weisen auf die Möglichkeit einer noch einfacheren Variation der Wendeleigenschaften hin.

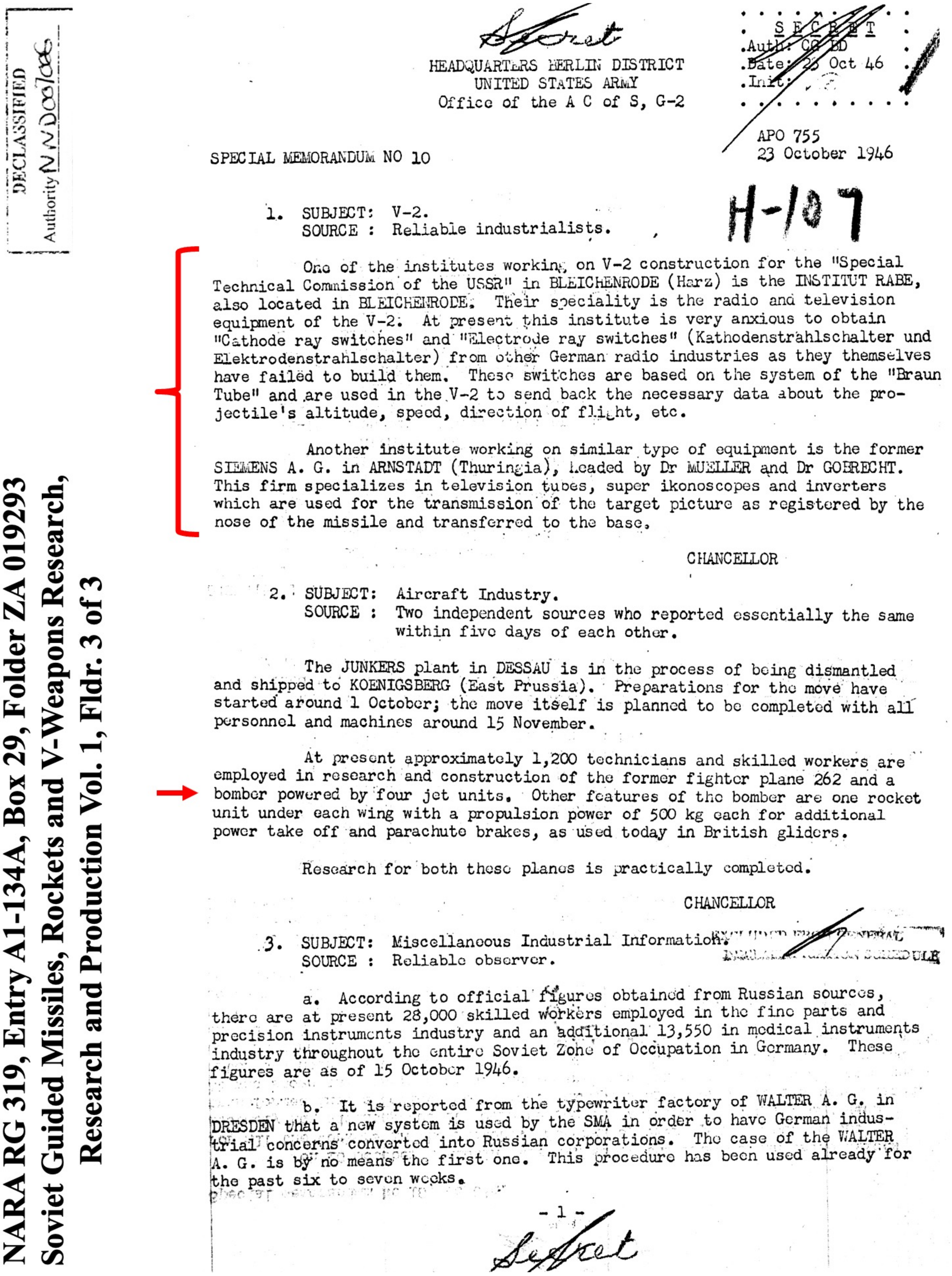
Im Jahre 1946 berichtete Kompfner [1] erstmalig über die Wanderfeldröhre (traveling-wave tube), die eine neuartige Laufzeitröhre für das Dezimeter- und Zentimetergebiet darstellt. 1947 veröffentlichte dann Pierce [2] eine umfassende Theorie, die die wichtigsten Eigenschaften dieser Röhre mit meist guter Annäherung wiedergibt. Der hier vorliegende grundsätzlich neue Mechanismus einer Wechselwirkung zwischen Welle und Elektronenstrahl und die überraschend guten Ergebnisse, die Kompfner bereits mit den ersten Verstärkerröhren dieser Art erzielte, regten schnell zu verhältnismäßig zahlreichen weiteren Untersuchungen an [3 bis 12]. Der experimentelle Anteil dieser Arbeiten ist aber noch nicht sehr umfangreich. Eigene Untersuchungen zeigten uns, daß z. B. der Bau von Verstärkern sehr durch eine leicht einsetzende Selbsterregung erschwert wird. Diese Selbsterregung wurde von Kompfner bereits erwähnt, aber nicht näher beschrieben. Um die Selbsterregung systematisch unterdrücken zu können, schien es uns daher zweckmäßig, sie experimentell zu untersuchen. Die erhaltenen Ergebnisse, über die im Folgenden berichtet wird, sind auch für die Theorie der Wanderfeldröhre, insbesondere für die Berechnung der Eigenschaften der Wendeln, interessant. Einige Besonderheiten des Schwingungsmechanismus könnten ferner dazu führen, daß die Wanderfeldröhre trotz ihres vorerst noch geringen Wirkungsgrades und des zur Zeit noch großen Aufwandes eine gewisse Bedeutung als Oszillatorröhre erhält, so z. B. für Meßsender mit besonderen Anforderungen, wie sie etwa die Einstellung der Frequenz über mehrere Oktaven durch ausschließliche Änderung einer Gleichspannung darstellt.

Aufbau und Funktion der Wanderfeldröhre

Den Aufbau der für die Messungen benutzten Wanderfeldröhren zeigt Bild 1. Die Röhre besteht aus zwei Hauptteilen: Der Elektronenspritze und der Wendel. Die Elektronenspritze erzeugt einen fadenförmigen Elektronenstrahl homogener Geschwindigkeit v_e, der die Wendel in Richtung der Achse durchläuft. Läßt man eine Welle auf der Wendel entlanglaufen, dann bewirkt die schraubenartige Struktur

Bild 1
a) Aufbau einer Wanderfeldröhre
b) Teil der Wendel mit Maßzahlen in mm

Figure B.262: It appears that Herbert Schnitger and Dieter Weber were not allowed to publish their own traveling wave tube work until much later, and much more quietly [Schnitger and Weber 1949].



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Authority NND007086

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HEADQUARTERS BERLIN DISTRICT
UNITED STATES ARMY
Office of the A C of S, G-2

~~SECRET~~
~~Auth: CG BD~~
~~Date: 23 Oct 46~~
~~Init:~~

APO 755
23 October 1946

SPECIAL MEMORANDUM NO 10

H-107

1. SUBJECT: V-2.
SOURCE : Reliable industrialists.

One of the institutes working on V-2 construction for the "Special Technical Commission of the USSR" in BLEICHENRODE (Harz) is the INSTITUT RABE, also located in BLEICHENRODE. Their speciality is the radio and television equipment of the V-2. At present this institute is very anxious to obtain "Cathode ray switches" and "Electrode ray switches" (Kathodenstrahlschalter und Elektrodenstrahlschalter) from other German radio industries as they themselves have failed to build them. These switches are based on the system of the "Braun Tube" and are used in the V-2 to send back the necessary data about the projectile's altitude, speed, direction of flight, etc.

Another institute working on similar type of equipment is the former SIEMENS A. G. in ARNSTADT (Thuringia), headed by Dr MUELLER and Dr GOBRECHT. This firm specializes in television tubes, super ikonoscopes and inverters which are used for the transmission of the target picture as registered by the nose of the missile and transferred to the base.

CHANCELLOR

2. SUBJECT: Aircraft Industry.
SOURCE : Two independent sources who reported essentially the same within five days of each other.

The JUNKERS plant in DESSAU is in the process of being dismantled and shipped to KOENIGSBERG (East Prussia). Preparations for the move have started around 1 October; the move itself is planned to be completed with all personnel and machines around 15 November.

At present approximately 1,200 technicians and skilled workers are employed in research and construction of the former fighter plane 262 and a bomber powered by four jet units. Other features of the bomber are one rocket unit under each wing with a propulsion power of 500 kg each for additional power take off and parachute brakes, as used today in British gliders.

Research for both these planes is practically completed.

CHANCELLOR

3. SUBJECT: Miscellaneous Industrial Information.
SOURCE : Reliable observer.

EXCLUDED FROM GENERAL
DECLASSIFICATION SCHEDULE

a. According to official figures obtained from Russian sources, there are at present 28,000 skilled workers employed in the fine parts and precision instruments industry and an additional 13,550 in medical instruments industry throughout the entire Soviet Zone of Occupation in Germany. These figures are as of 15 October 1946.

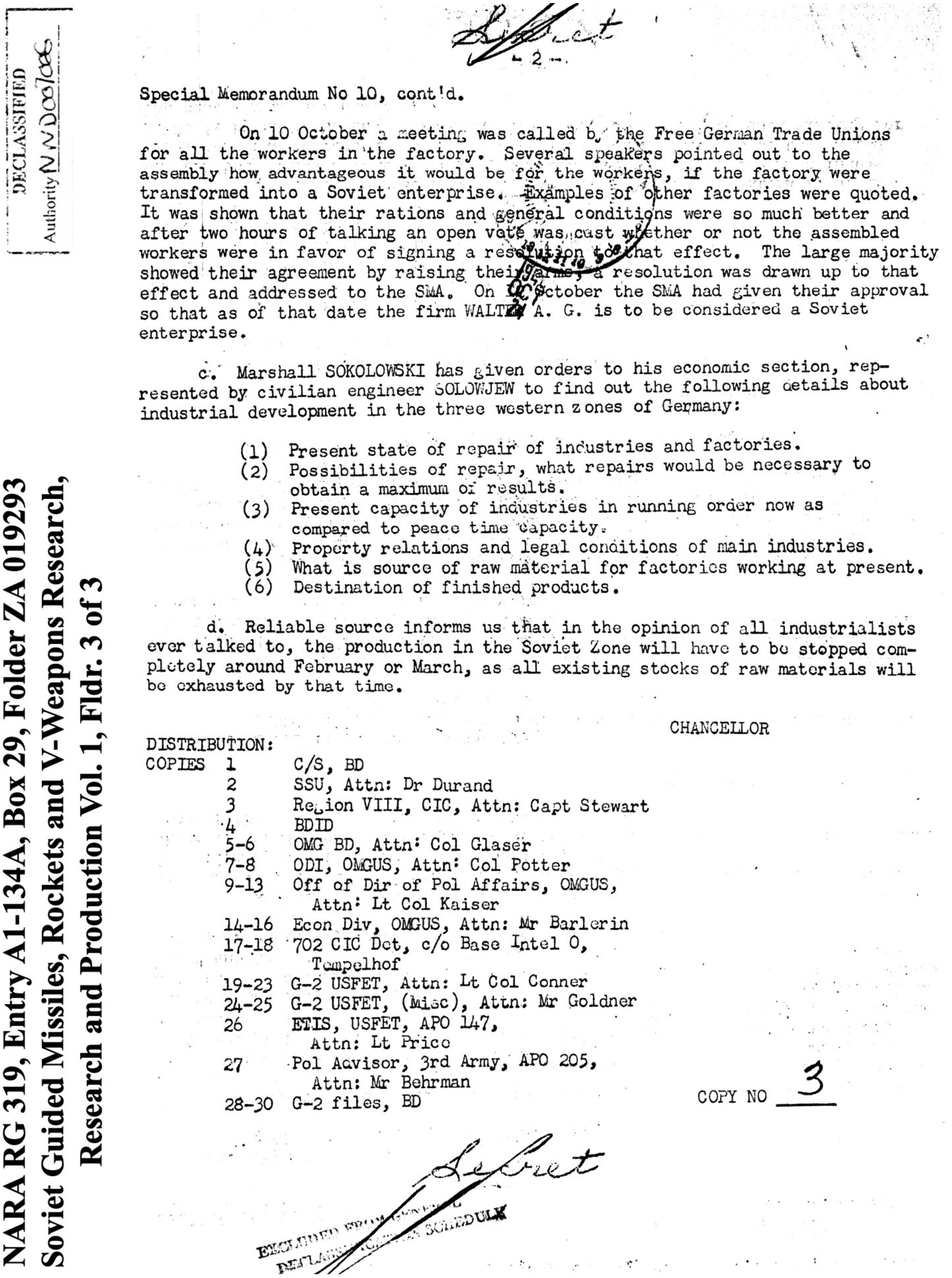
b. It is reported from the typewriter factory of WALTER A. G. in DRESDEN that a new system is used by the SMA in order to have German industrial concerns converted into Russian corporations. The case of the WALTER A. G. is by no means the first one. This procedure has been used already for the past six to seven weeks.

\- 1 -

Secret

NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293
Soviet Guided Missiles, Rockets and V-Weapons Research,
Research and Production Vol. 1, Fldr. 3 of 3

Figure B.263: 1946 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 3 of 3]. See also Section E.2.



Secret

- 2 -

Special Memorandum No 10, cont'd.

On 10 October a meeting was called by the Free German Trade Unions for all the workers in the factory. Several speakers pointed out to the assembly how advantageous it would be for the workers, if the factory were transformed into a Soviet enterprise. Examples of other factories were quoted. It was shown that their rations and general conditions were so much better and after two hours of talking an open vote was cast whether or not the assembled workers were in favor of signing a resolution to that effect. The large majority showed their agreement by raising their arms, a resolution was drawn up to that effect and addressed to the SMA. On [illegible] October the SMA had given their approval so that as of that date the firm WALTER A. G. is to be considered a Soviet enterprise.

c. Marshall SOKOLOWSKI has given orders to his economic section, represented by civilian engineer SOLOWJEW to find out the following details about industrial development in the three western zones of Germany:

(1) Present state of repair of industries and factories.
(2) Possibilities of repair, what repairs would be necessary to obtain a maximum of results.
(3) Present capacity of industries in running order now as compared to peace time capacity.
(4) Property relations and legal conditions of main industries.
(5) What is source of raw material for factories working at present.
(6) Destination of finished products.

d. Reliable source informs us that in the opinion of all industrialists ever talked to, the production in the Soviet Zone will have to be stopped completely around February or March, as all existing stocks of raw materials will be exhausted by that time.

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	17-18	702 CIC Det, c/o Base Intel O, Tempelhof
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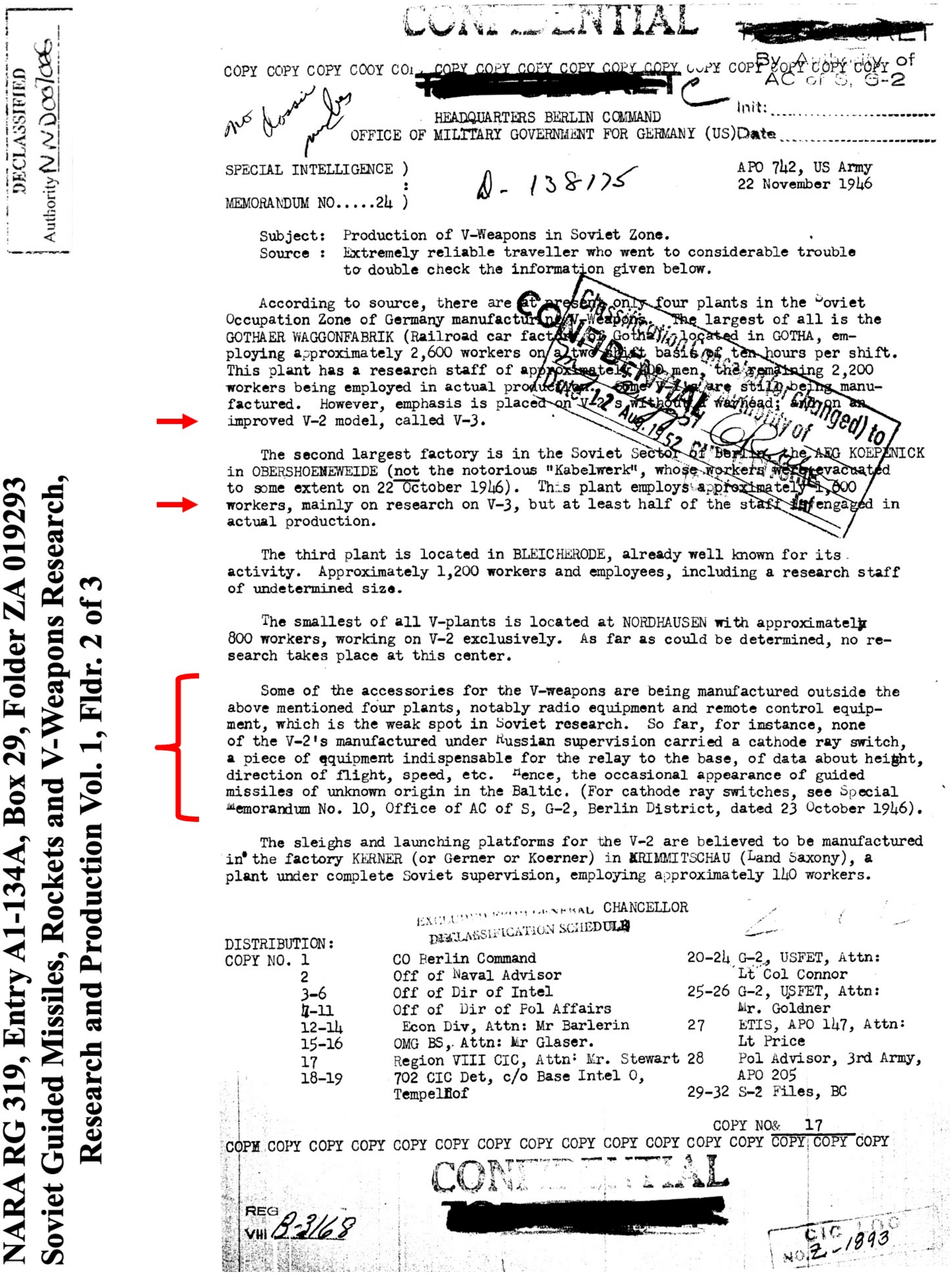
Soviet Guided Missiles, Rockets and V-Weapons Research,
Research and Production Vol. 1, Fldr. 3 of 3

Figure B.264: 1946 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 3 of 3]. See also Section E.2.



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By Authority of
AC of S, G-2
Init: ....
Date ....

no dossier made

HEADQUARTERS BERLIN COMMAND
OFFICE OF MILITARY GOVERNMENT FOR GERMANY (US)

SPECIAL INTELLIGENCE)
:
MEMORANDUM NO.....24)

D-138175

APO 742, US Army
22 November 1946

Subject: Production of V-Weapons in Soviet Zone.
Source : Extremely reliable traveller who went to considerable trouble to double check the information given below.

According to source, there are at present only four plants in the Soviet Occupation Zone of Germany manufacturing V-Weapons. The largest of all is the GOTHAER WAGGONFABRIK (Railroad car factory of Gotha), located in GOTHA, employing approximately 2,600 workers on a two shift basis of ten hours per shift. This plant has a research staff of approximately 400 men, the remaining 2,200 workers being employed in actual production. Some V-1's are still being manufactured. However, emphasis is placed on V-2's without a warhead; and on an improved V-2 model, called V-3.

The second largest factory is in the Soviet Sector of Berlin, the AEG KOEPENICK in OBERSHOENEWEIDE (not the notorious "Kabelwerk", whose workers were evacuated to some extent on 22 October 1946). This plant employs approximately 1,600 workers, mainly on research on V-3, but at least half of the staff is engaged in actual production.

Classification (cancelled) (changed) to
CONFIDENTIAL
By authority of
Date 12 Aug. 1952

The third plant is located in BLEICHERODE, already well known for its activity. Approximately 1,200 workers and employees, including a research staff of undetermined size.

The smallest of all V-plants is located at NORDHAUSEN with approximately 800 workers, working on V-2 exclusively. As far as could be determined, no research takes place at this center.

Some of the accessories for the V-weapons are being manufactured outside the above mentioned four plants, notably radio equipment and remote control equipment, which is the weak spot in Soviet research. So far, for instance, none of the V-2's manufactured under Russian supervision carried a cathode ray switch, a piece of equipment indispensable for the relay to the base, of data about height, direction of flight, speed, etc. Hence, the occasional appearance of guided missiles of unknown origin in the Baltic. (For cathode ray switches, see Special Memorandum No. 10, Office of AC of S, G-2, Berlin District, dated 23 October 1946).

The sleighs and launching platforms for the V-2 are believed to be manufactured in the factory KERNER (or Gerner or Koerner) in KRIMMITSCHAU (Land Saxony), a plant under complete Soviet supervision, employing approximately 140 workers.

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REG VIII B-3168

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Soviet Guided Missiles, Rockets and V-Weapons Research,
Research and Production Vol. 1, Fldr. 2 of 3

Figure B.265: 1946 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3]. See also Section E.2.

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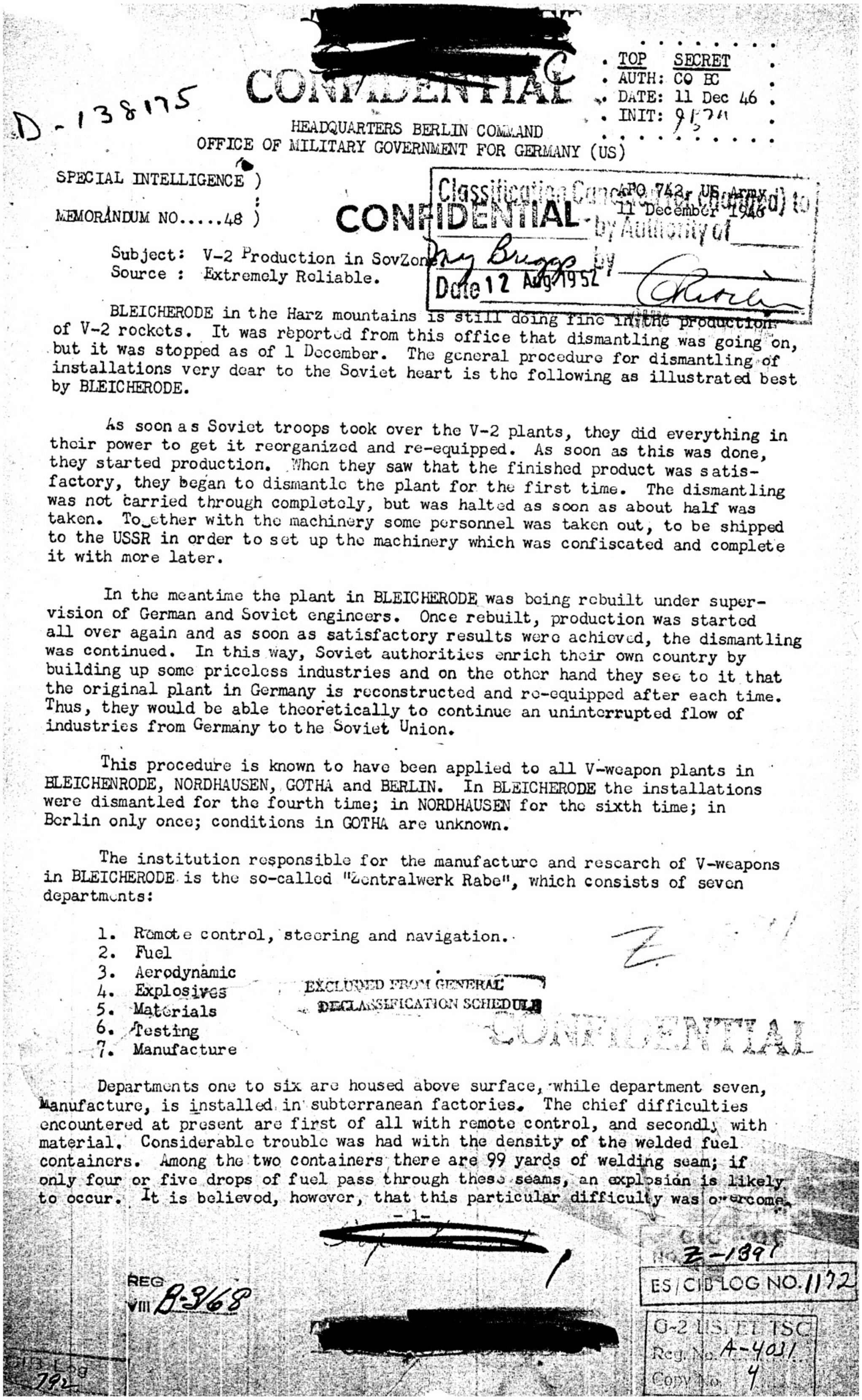

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D-138175

HEADQUARTERS BERLIN COMMAND
OFFICE OF MILITARY GOVERNMENT FOR GERMANY (US)

SPECIAL INTELLIGENCE)
MEMORANDUM NO.....48)

APO 742, US Army
11 December 1946

CONFIDENTIAL

Classification Cancelled (Changed) to CONFIDENTIAL by Authority of Maj Briggs by
Date 12 Aug 1952

Subject: V-2 Production in SovZone
Source : Extremely Reliable.

BLEICHERODE in the Harz mountains is still doing fine in the production of V-2 rockets. It was reported from this office that dismantling was going on, but it was stopped as of 1 December. The general procedure for dismantling of installations very dear to the Soviet heart is the following as illustrated best by BLEICHERODE.

As soon as Soviet troops took over the V-2 plants, they did everything in their power to get it reorganized and re-equipped. As soon as this was done, they started production. When they saw that the finished product was satisfactory, they began to dismantle the plant for the first time. The dismantling was not carried through completely, but was halted as soon as about half was taken. Together with the machinery some personnel was taken out, to be shipped to the USSR in order to set up the machinery which was confiscated and complete it with more later.

In the meantime the plant in BLEICHERODE was being rebuilt under supervision of German and Soviet engineers. Once rebuilt, production was started all over again and as soon as satisfactory results were achieved, the dismantling was continued. In this way, Soviet authorities enrich their own country by building up some priceless industries and on the other hand they see to it that the original plant in Germany is reconstructed and re-equipped after each time. Thus, they would be able theoretically to continue an uninterrupted flow of industries from Germany to the Soviet Union.

This procedure is known to have been applied to all V-weapon plants in BLEICHENRODE, NORDHAUSEN, GOTHA and BERLIN. In BLEICHERODE the installations were dismantled for the fourth time; in NORDHAUSEN for the sixth time; in Berlin only once; conditions in GOTHA are unknown.

The institution responsible for the manufacture and research of V-weapons in BLEICHERODE is the so-called "Zentralwerk Rabe", which consists of seven departments:

1. Remote control, steering and navigation.
2. Fuel
3. Aerodynamic
4. Explosives
5. Materials
6. Testing
7. Manufacture

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Departments one to six are housed above surface, while department seven, Manufacture, is installed in subterranean factories. The chief difficulties encountered at present are first of all with remote control, and secondly with material. Considerable trouble was had with the density of the welded fuel containers. Among the two containers there are 99 yards of welding seam; if only four or five drops of fuel pass through these seams, an explosion is likely to occur. It is believed, however, that this particular difficulty was overcome.

- 1 -

[redacted]

No. Z-1391

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Figure B.266: 1946 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3]. See also Section E.2.

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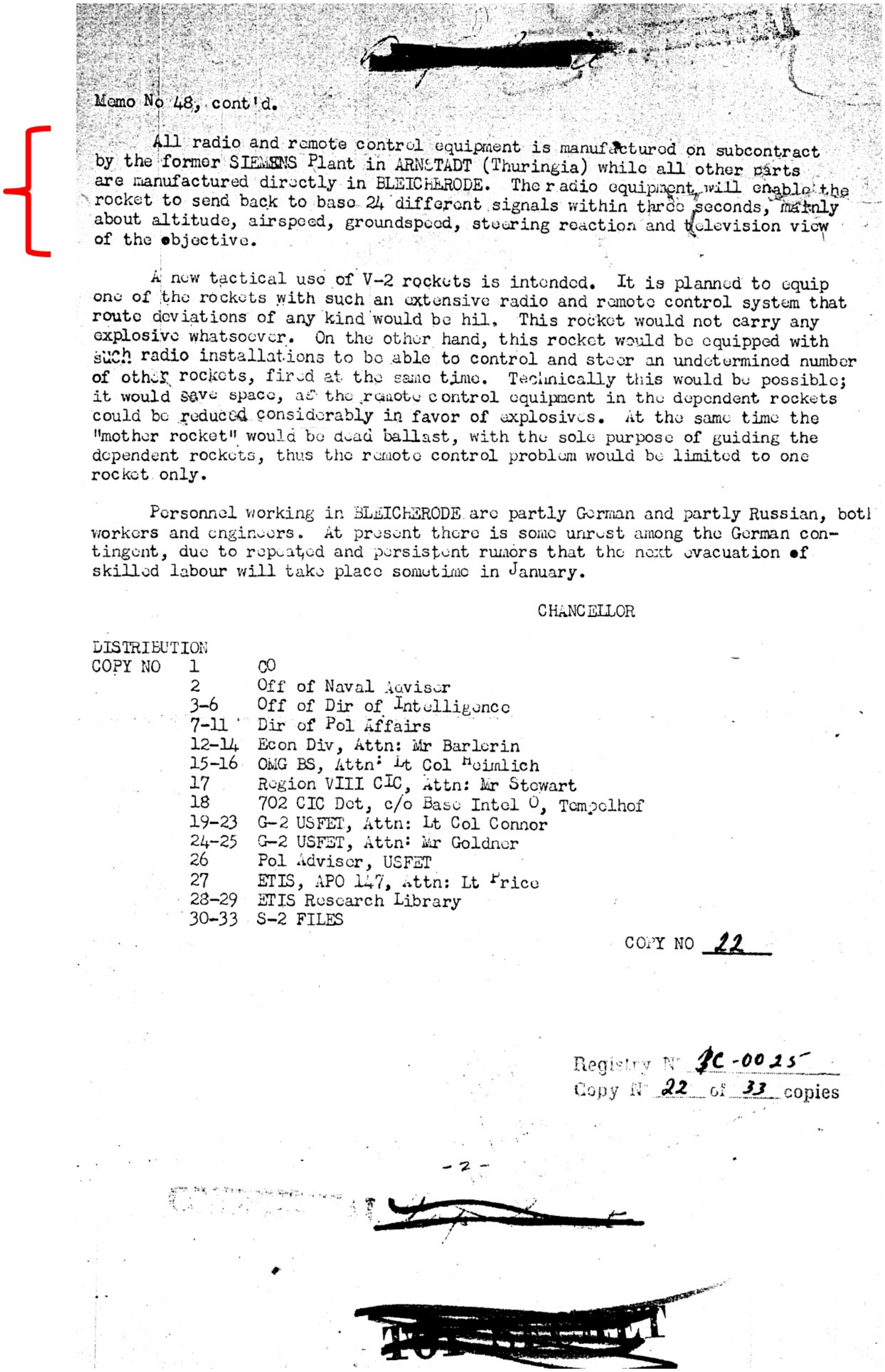

[redacted]

Memo No 48, cont'd.

All radio and remote control equipment is manufactured on subcontract by the former SIEMENS Plant in ARNSTADT (Thuringia) while all other parts are manufactured directly in BLEICHERODE. The radio equipment will enable the rocket to send back to base 24 different signals within three seconds, mainly about altitude, airspeed, groundspeed, steering reaction and television view of the objective.

A new tactical use of V-2 rockets is intended. It is planned to equip one of the rockets with such an extensive radio and remote control system that route deviations of any kind would be hil. This rocket would not carry any explosive whatsoever. On the other hand, this rocket would be equipped with such radio installations to be able to control and steer an undetermined number of other rockets, fired at the same time. Technically this would be possible; it would save space, as the remote control equipment in the dependent rockets could be reduced considerably in favor of explosives. At the same time the "mother rocket" would be dead ballast, with the sole purpose of guiding the dependent rockets, thus the remote control problem would be limited to one rocket only.

Personnel working in BLEICHERODE are partly German and partly Russian, both workers and engineers. At present there is some unrest among the German contingent, due to repeated and persistent rumors that the next evacuation of skilled labour will take place sometime in January.

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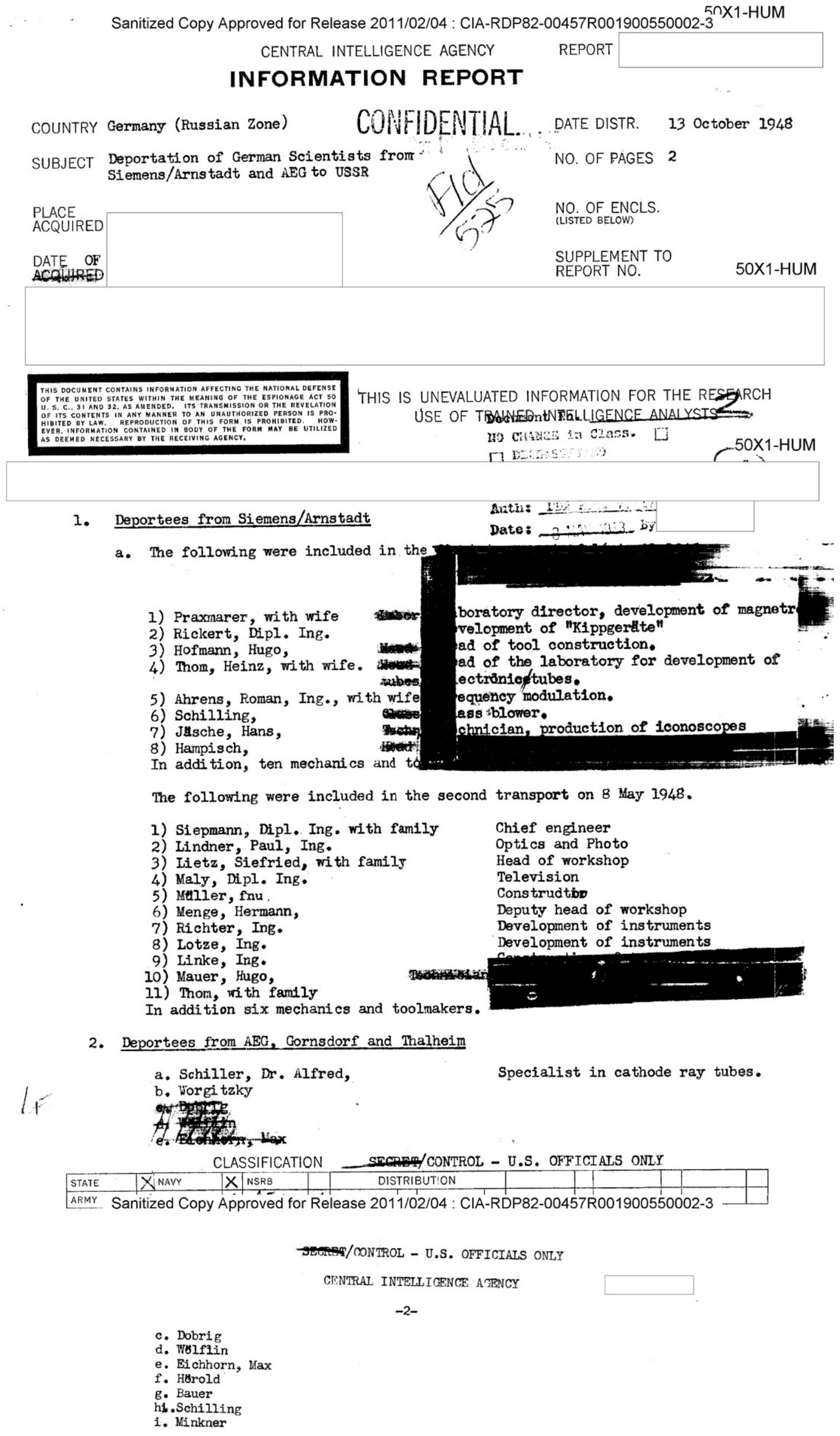
Research and Production Vol. 1, Fldr. 2 of 3

Figure B.267: 1946 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3]. See also Section E.2.



50X1-HUM

CENTRAL INTELLIGENCE AGENCY

REPORT

INFORMATION REPORT

CONFIDENTIAL

COUNTRY Germany (Russian Zone)

DATE DISTR. 13 October 1948

SUBJECT Deportation of German Scientists from Siemens/Arnstadt and AEG to USSR

NO. OF PAGES 2

Fld 525

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1. Deportees from Siemens/Arnstadt

a. The following were included in the [redacted]

1) Praxmarer, with wife boratory director, development of magnetr
2) Rickert, Dipl. Ing. velopment of "Kippgeräte"
3) Hofmann, Hugo, ad of tool construction.
4) Thom, Heinz, with wife. ad of the laboratory for development of ectronic tubes.
5) Ahrens, Roman, Ing., with wife equency modulation.
6) Schilling, ass blower.
7) Jäsche, Hans, chnician, production of iconoscopes
8) Hampisch,
In addition, ten mechanics and to

The following were included in the second transport on 8 May 1948.

1) Siepmann, Dipl. Ing. with family	Chief engineer
2) Lindner, Paul, Ing.	Optics and Photo
3) Lietz, Siefried, with family	Head of workshop
4) Maly, Dipl. Ing.	Television
5) Müller, fnu.	Construdtor
6) Menge, Hermann,	Deputy head of workshop
7) Richter, Ing.	Development of instruments
8) Lotze, Ing.	Development of instruments
9) Linke, Ing.	[redacted]
10) Mauer, Hugo,	
11) Thom, with family	

In addition six mechanics and toolmakers.

2. Deportees from AEG, Gornsdorf and Thalheim

a. Schiller, Dr. Alfred, Specialist in cathode ray tubes.
b. Worgitzky
~~c. Dobrig~~
~~d. Wölflin~~
~~e. Eichhorn, Max~~

LF

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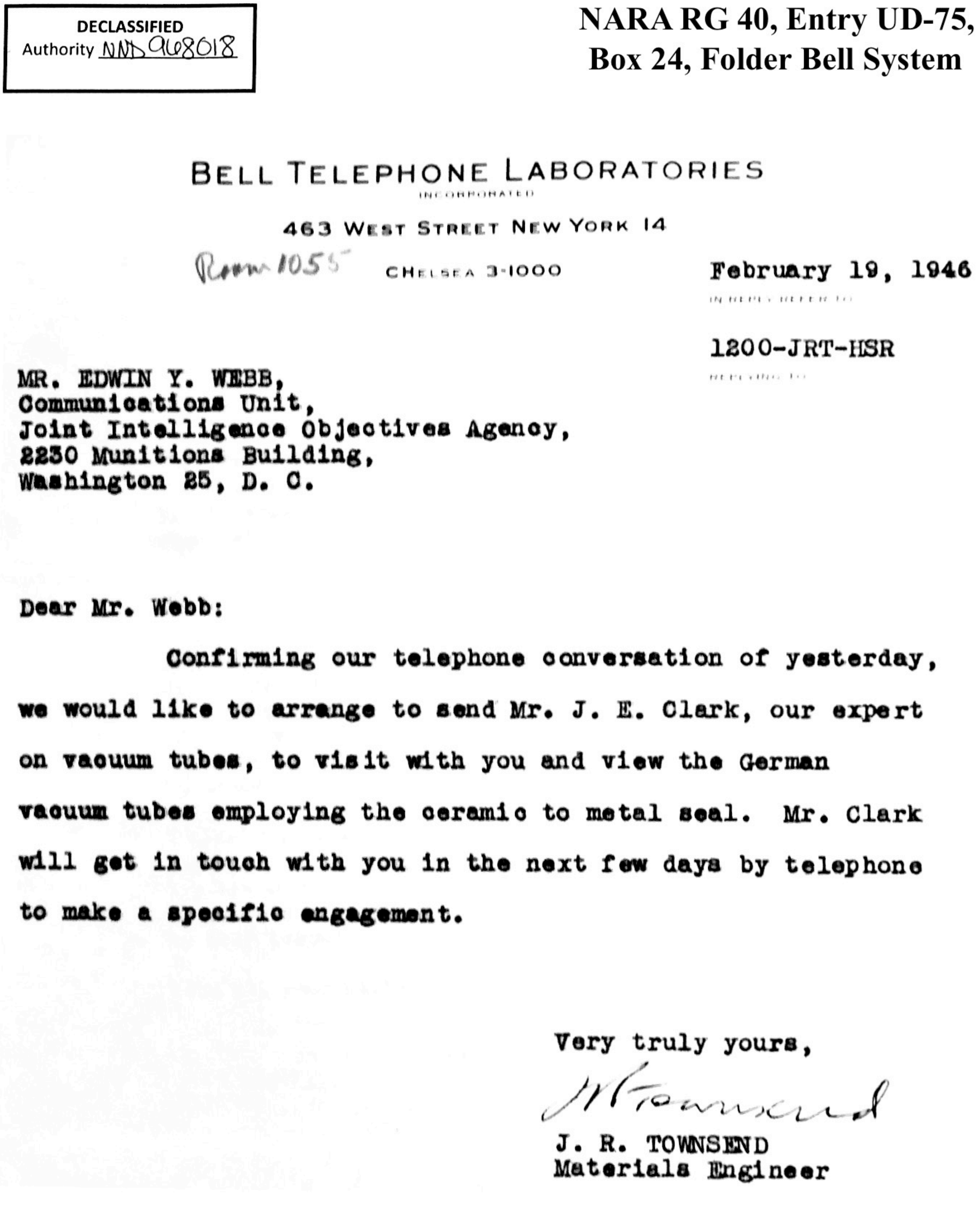
CENTRAL INTELLIGENCE AGENCY

-2-

c. Dobrig
d. Wölflin
e. Eichhorn, Max
f. Hörold
g. Bauer
h. Schilling
i. Minkner

Figure B.268: 1948 U.S. intelligence reports described the struggles of Soviet occupation forces to reconstruct the wartime German work on traveling wave tubes and rocket guidance systems without the evacuated scientists/materials/information, thereby confirming the details of the wartime work [https://www.cia.gov/readingroom/document/cia-rdp82-00457r001900550002-3]. See also Section E.2.



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February 19, 1946
IN REPLY REFER TO

1200-JRT-HSR
REFERRING TO

MR. EDWIN Y. WEBB,
Communications Unit,
Joint Intelligence Objectives Agency,
2230 Munitions Building,
Washington 25, D. C.

Dear Mr. Webb:

Confirming our telephone conversation of yesterday, we would like to arrange to send Mr. J. E. Clark, our expert on vacuum tubes, to visit with you and view the German vacuum tubes employing the ceramic to metal seal. Mr. Clark will get in touch with you in the next few days by telephone to make a specific engagement.

Very truly yours,

J R Townsend

J. R. TOWNSEND
Materials Engineer

Figure B.269: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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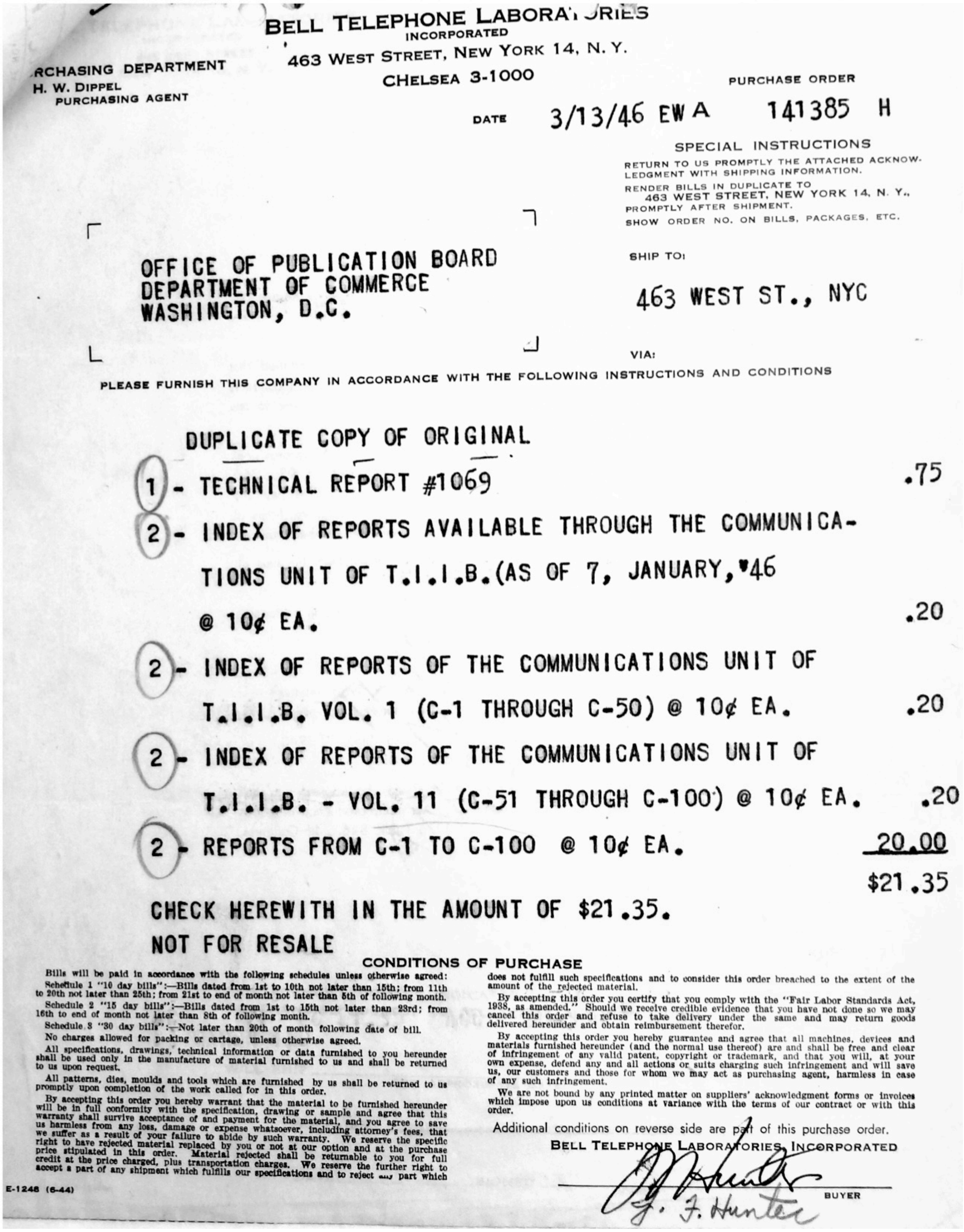

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By accepting this order you hereby warrant that the material to be furnished hereunder will be in full conformity with the specification, drawing or sample and agree that this warranty shall survive acceptance of and payment for the material, and you agree to save us harmless from any loss, damage or expense whatsoever, including attorney's fees, that we suffer as a result of your failure to abide by such warranty. We reserve the specific right to have rejected material replaced by you or not at our option and at the purchase price stipulated in this order. Material rejected shall be returnable to you for full credit at the price charged, plus transportation charges. We reserve the further right to accept a part of any shipment which fulfills our specifications and to reject any part which does not fulfill such specifications and to consider this order breached to the extent of the amount of the rejected material.

By accepting this order you certify that you comply with the "Fair Labor Standards Act, 1938, as amended." Should we receive credible evidence that you have not done so we may cancel this order and refuse to take delivery under the same and may return goods delivered hereunder and obtain reimbursement therefor.

By accepting this order you hereby guarantee and agree that all machines, devices and materials furnished hereunder (and the normal use thereof) are and shall be free and clear of infringement of any valid patent, copyright or trademark, and that you will, at your own expense, defend any and all actions or suits charging such infringement and will save us, our customers and those for whom we may act as purchasing agent, harmless in case of any such infringement.

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Additional conditions on reverse side are part of this purchase order.

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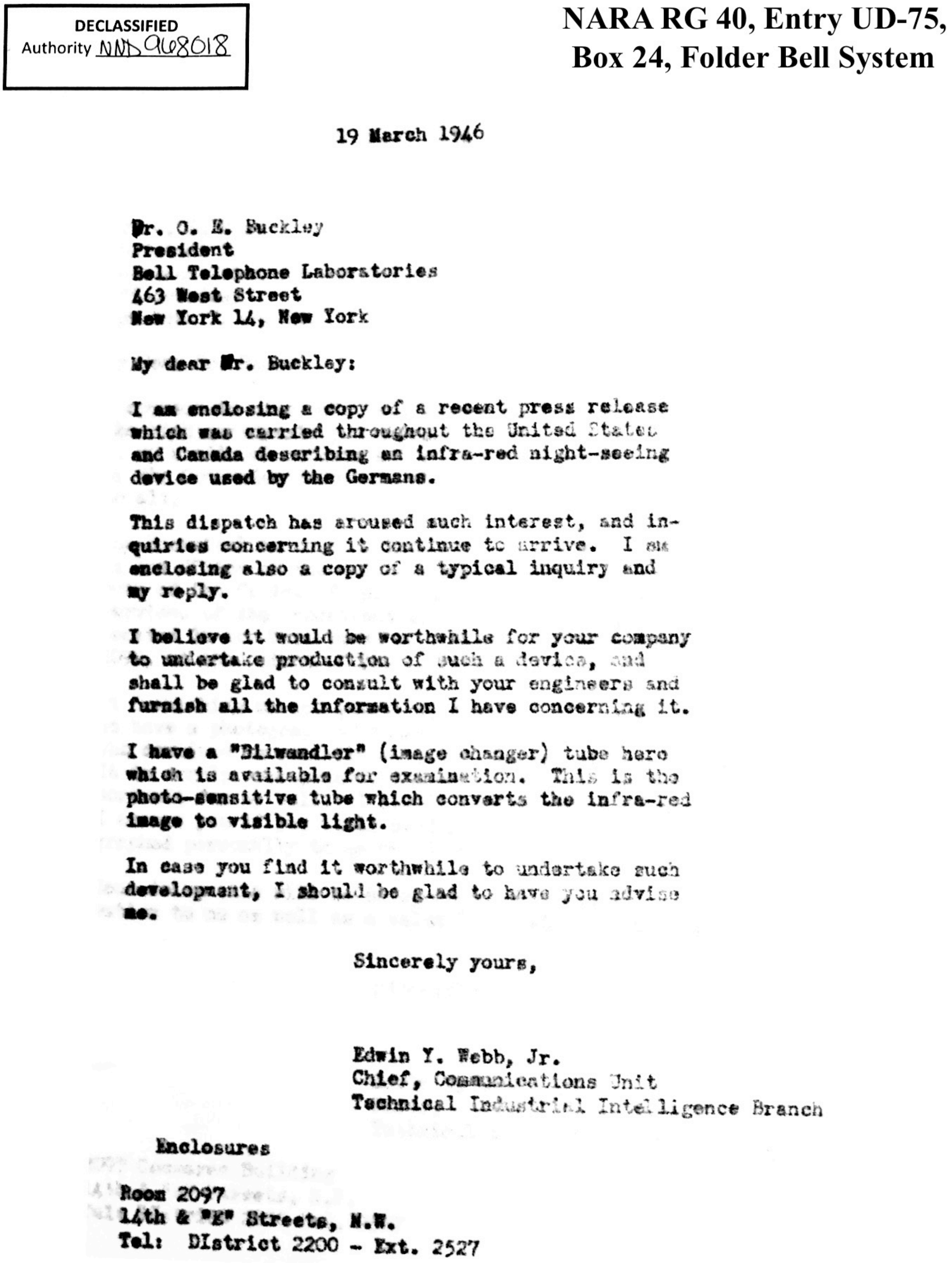
Figure B.270: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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NARA RG 40, Entry UD-75, Box 24, Folder Bell System

19 March 1946

Mr. O. E. Buckley
President
Bell Telephone Laboratories
463 West Street
New York 14, New York

My dear Mr. Buckley:

I am enclosing a copy of a recent press release which was carried throughout the United States and Canada describing an infra-red night-seeing device used by the Germans.

This dispatch has aroused such interest, and inquiries concerning it continue to arrive. I am enclosing also a copy of a typical inquiry and my reply.

I believe it would be worthwhile for your company to undertake production of such a device, and shall be glad to consult with your engineers and furnish all the information I have concerning it.

I have a "Bilwandler" (image changer) tube here which is available for examination. This is the photo-sensitive tube which converts the infra-red image to visible light.

In case you find it worthwhile to undertake such development, I should be glad to have you advise me.

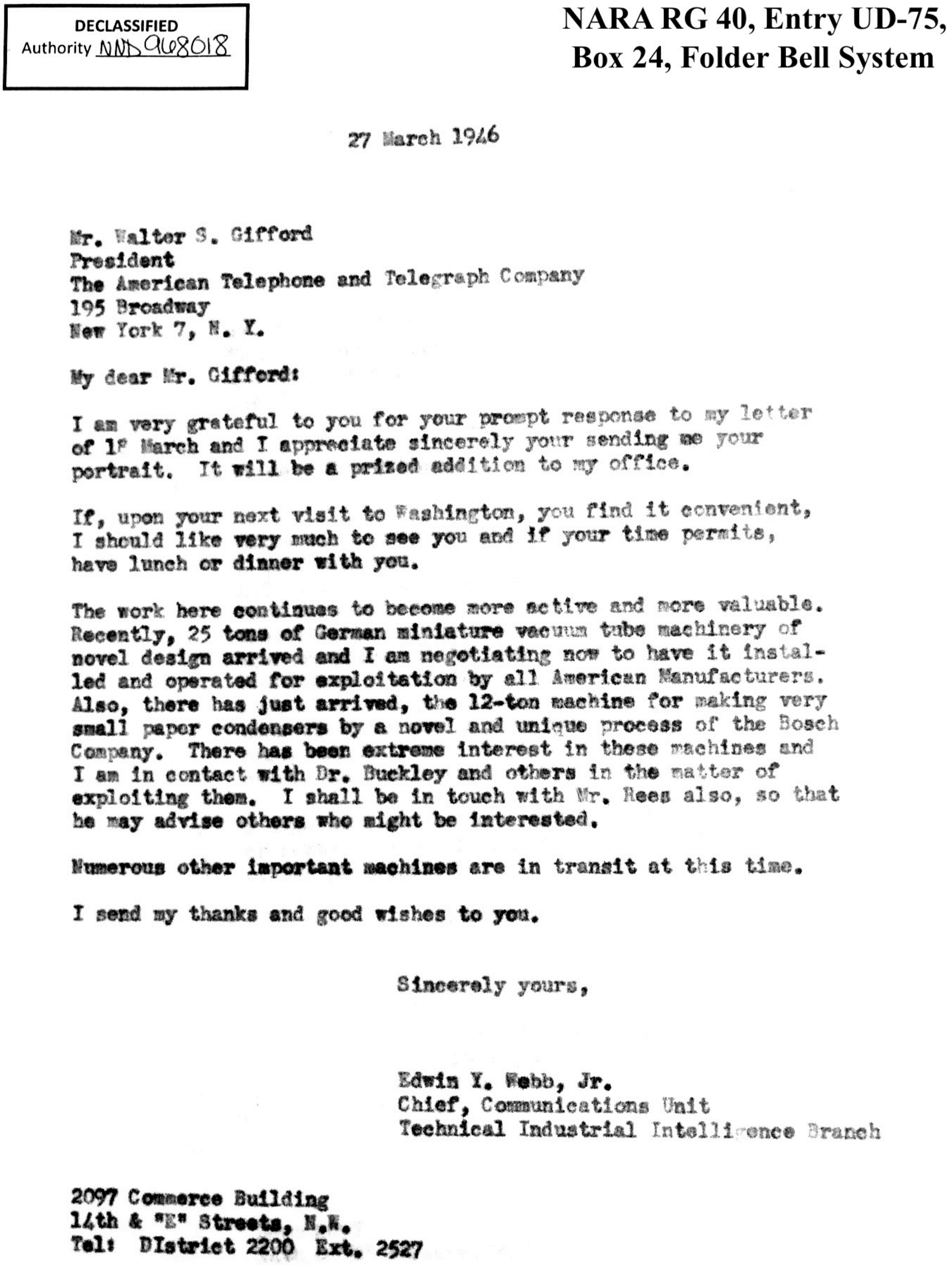
Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit
Technical Industrial Intelligence Branch

Enclosures

Room 2097
14th & "E" Streets, N.W.
Tel: DIstrict 2200 - Ext. 2527

Figure B.271: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

27 March 1946

Mr. Walter S. Gifford
President
The American Telephone and Telegraph Company
195 Broadway
New York 7, N. Y.

My dear Mr. Gifford:

I am very grateful to you for your prompt response to my letter of 18 March and I appreciate sincerely your sending me your portrait. It will be a prized addition to my office.

If, upon your next visit to Washington, you find it convenient, I should like very much to see you and if your time permits, have lunch or dinner with you.

The work here continues to become more active and more valuable. Recently, 25 tons of German miniature vacuum tube machinery of novel design arrived and I am negotiating now to have it installed and operated for exploitation by all American Manufacturers. Also, there has just arrived, the 12-ton machine for making very small paper condensers by a novel and unique process of the Bosch Company. There has been extreme interest in these machines and I am in contact with Dr. Buckley and others in the matter of exploiting them. I shall be in touch with Mr. Rees also, so that he may advise others who might be interested.

Numerous other important machines are in transit at this time.

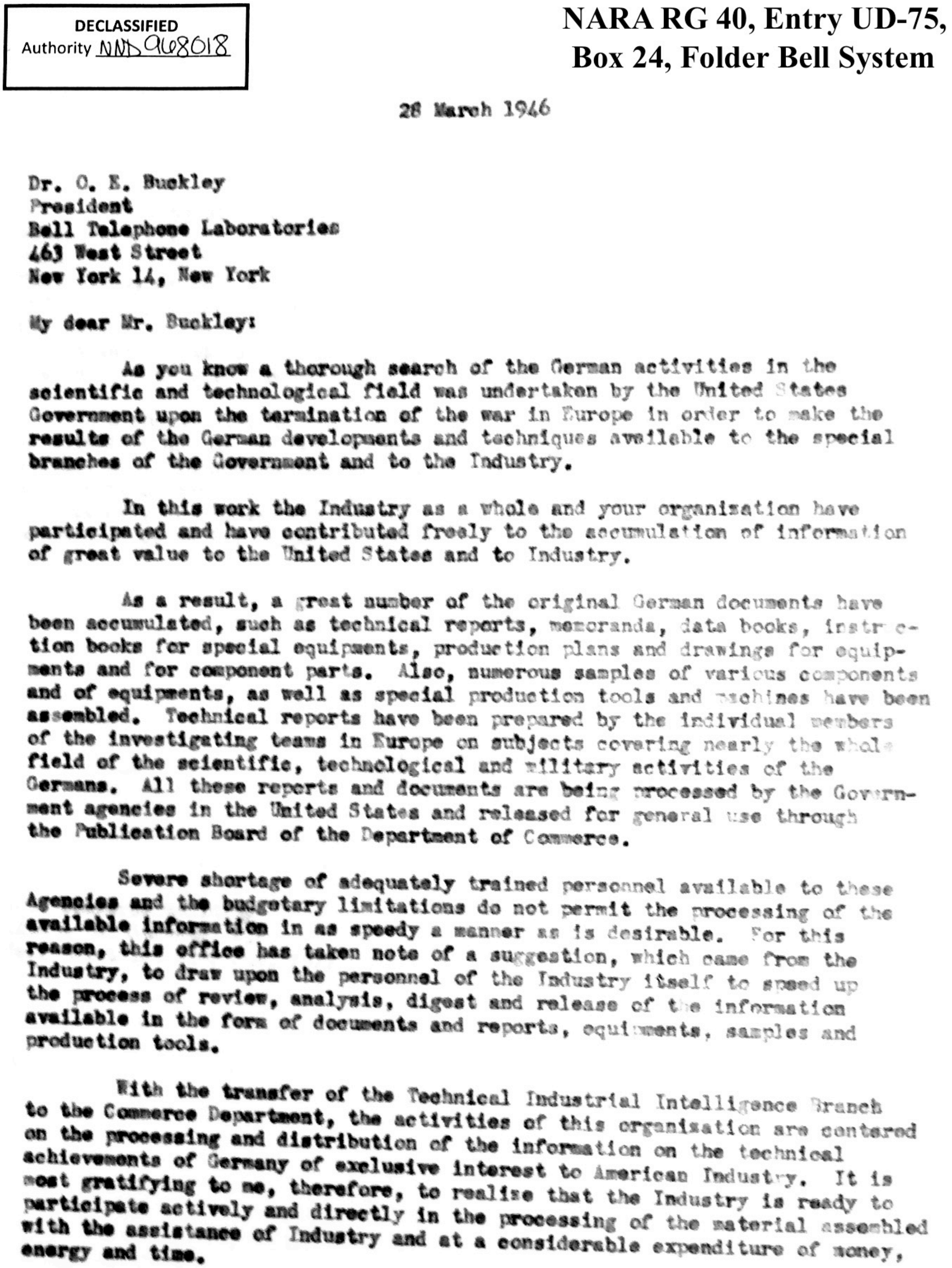
I send my thanks and good wishes to you.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit
Technical Industrial Intelligence Branch

2097 Commerce Building
14th & "E" Streets, N.W.
Tel: DIstrict 2200 Ext. 2527

Figure B.272: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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NARA RG 40, Entry UD-75,
Box 24, Folder Bell System

28 March 1946

Dr. O. E. Buckley
President
Bell Telephone Laboratories
463 West Street
New York 14, New York

My dear Mr. Buckley:

As you know a thorough search of the German activities in the scientific and technological field was undertaken by the United States Government upon the termination of the war in Europe in order to make the results of the German developments and techniques available to the special branches of the Government and to the Industry.

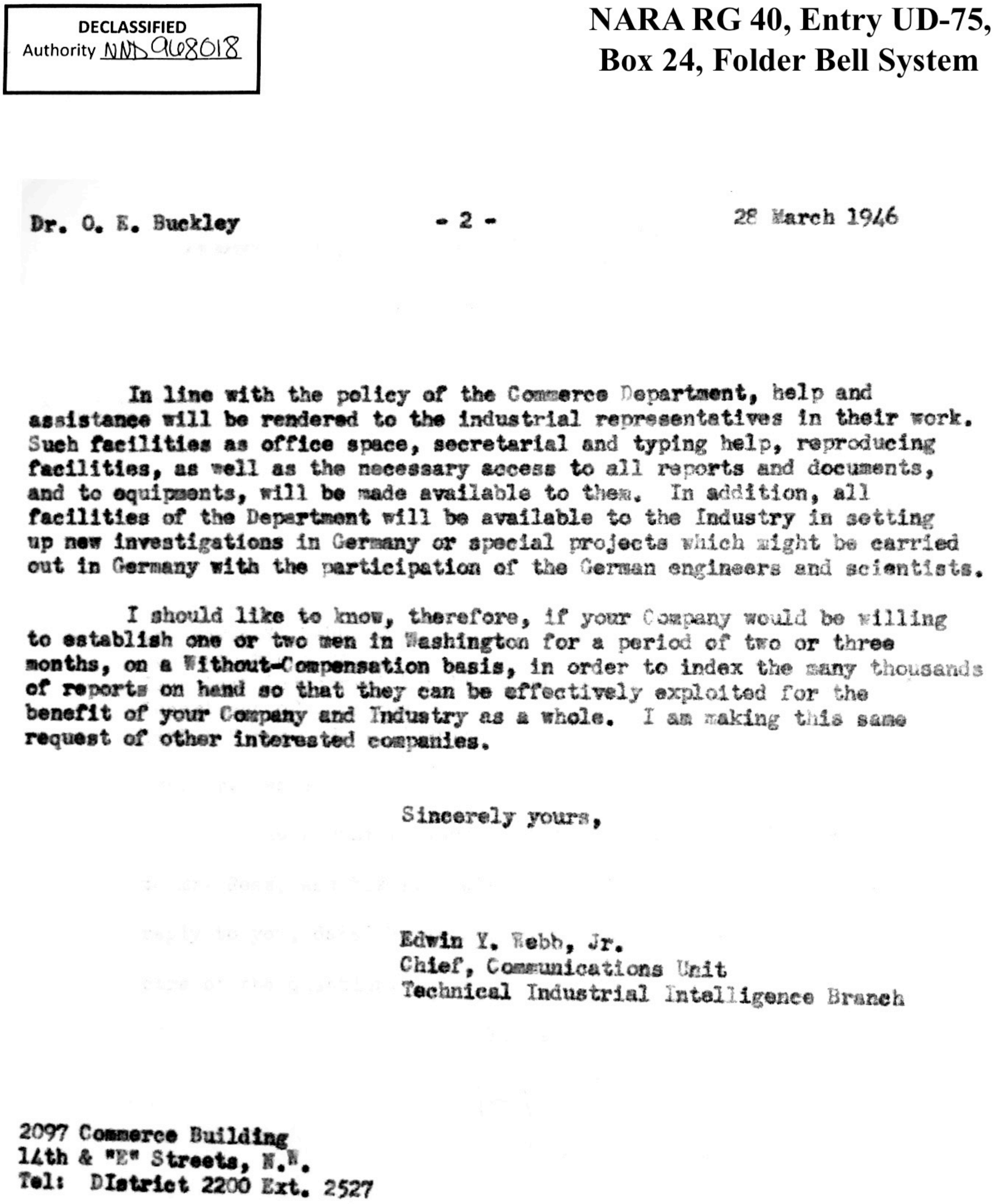
In this work the Industry as a whole and your organization have participated and have contributed freely to the accumulation of information of great value to the United States and to Industry.

As a result, a great number of the original German documents have been accumulated, such as technical reports, memoranda, data books, instruction books for special equipments, production plans and drawings for equipments and for component parts. Also, numerous samples of various components and of equipments, as well as special production tools and machines have been assembled. Technical reports have been prepared by the individual members of the investigating teams in Europe on subjects covering nearly the whole field of the scientific, technological and military activities of the Germans. All these reports and documents are being processed by the Government agencies in the United States and released for general use through the Publication Board of the Department of Commerce.

Severe shortage of adequately trained personnel available to these Agencies and the budgetary limitations do not permit the processing of the available information in as speedy a manner as is desirable. For this reason, this office has taken note of a suggestion, which came from the Industry, to draw upon the personnel of the Industry itself to speed up the process of review, analysis, digest and release of the information available in the form of documents and reports, equipments, samples and production tools.

With the transfer of the Technical Industrial Intelligence Branch to the Commerce Department, the activities of this organization are centered on the processing and distribution of the information on the technical achievements of Germany of exclusive interest to American Industry. It is most gratifying to me, therefore, to realize that the Industry is ready to participate actively and directly in the processing of the material assembled with the assistance of Industry and at a considerable expenditure of money, energy and time.

Figure B.273: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

Dr. O. E. Buckley - 2 - 28 March 1946

In line with the policy of the Commerce Department, help and assistance will be rendered to the industrial representatives in their work. Such facilities as office space, secretarial and typing help, reproducing facilities, as well as the necessary access to all reports and documents, and to equipments, will be made available to them. In addition, all facilities of the Department will be available to the Industry in setting up new investigations in Germany or special projects which might be carried out in Germany with the participation of the German engineers and scientists.

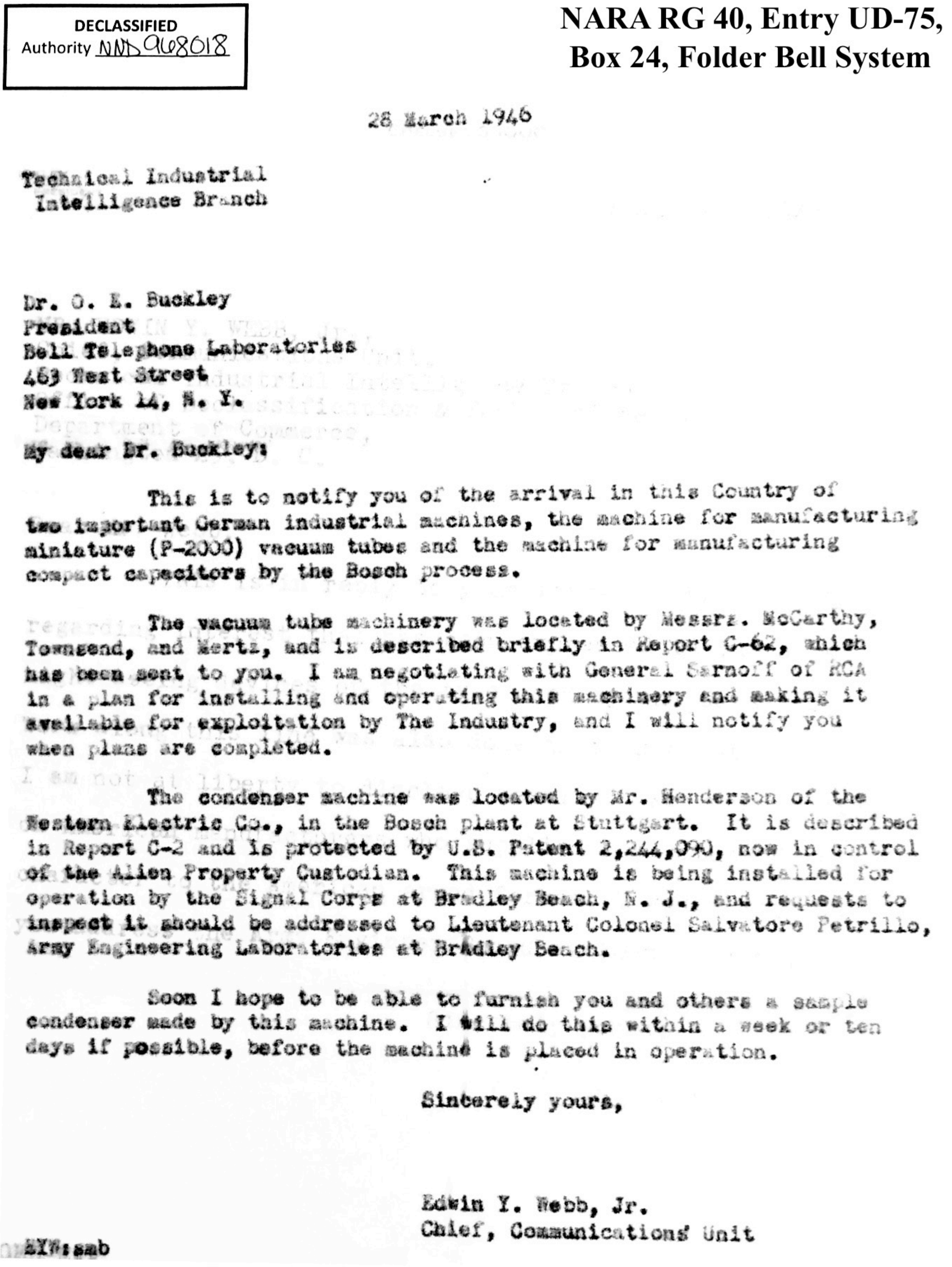
I should like to know, therefore, if your Company would be willing to establish one or two men in Washington for a period of two or three months, on a Without-Compensation basis, in order to index the many thousands of reports on hand so that they can be effectively exploited for the benefit of your Company and Industry as a whole. I am making this same request of other interested companies.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit
Technical Industrial Intelligence Branch

2097 Commerce Building
14th & "E" Streets, N.W.
Tel: DIstrict 2200 Ext. 2527

Figure B.274: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

28 March 1946

Technical Industrial
Intelligence Branch

Dr. O. E. Buckley
President
Bell Telephone Laboratories
463 West Street
New York 14, N. Y.

My dear Dr. Buckley:

This is to notify you of the arrival in this Country of two important German industrial machines, the machine for manufacturing miniature (P-2000) vacuum tubes and the machine for manufacturing compact capacitors by the Bosch process.

The vacuum tube machinery was located by Messrs. McCarthy, Townsend, and Mertz, and is described briefly in Report C-62, which has been sent to you. I am negotiating with General Sarnoff of RCA in a plan for installing and operating this machinery and making it available for exploitation by The Industry, and I will notify you when plans are completed.

The condenser machine was located by Mr. Henderson of the Western Electric Co., in the Bosch plant at Stuttgart. It is described in Report C-2 and is protected by U.S. Patent 2,244,090, now in control of the Alien Property Custodian. This machine is being installed for operation by the Signal Corps at Bradley Beach, N. J., and requests to inspect it should be addressed to Lieutenant Colonel Salvatore Petrillo, Army Engineering Laboratories at Bradley Beach.

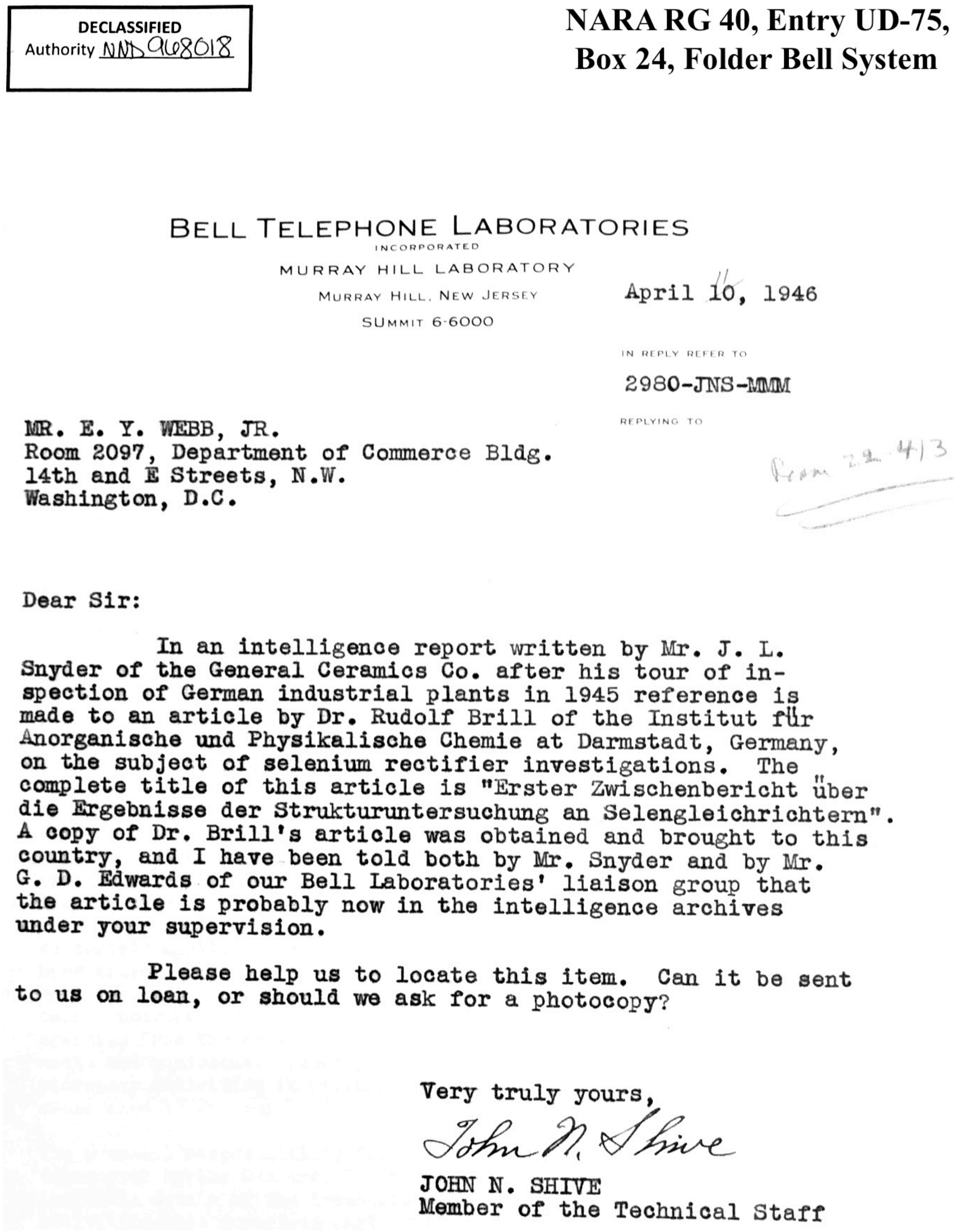
Soon I hope to be able to furnish you and others a sample condenser made by this machine. I will do this within a week or ten days if possible, before the machine is placed in operation.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit

EYW:smb

Figure B.275: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

BELL TELEPHONE LABORATORIES
INCORPORATED
MURRAY HILL LABORATORY
MURRAY HILL, NEW JERSEY
SUMMIT 6-6000

April 16, 1946

IN REPLY REFER TO
2980-JNS-MMM

REPLYING TO

Room 22-413

MR. E. Y. WEBB, JR.
Room 2097, Department of Commerce Bldg.
14th and E Streets, N.W.
Washington, D.C.

Dear Sir:

In an intelligence report written by Mr. J. L. Snyder of the General Ceramics Co. after his tour of inspection of German industrial plants in 1945 reference is made to an article by Dr. Rudolf Brill of the Institut für Anorganische und Physikalische Chemie at Darmstadt, Germany, on the subject of selenium rectifier investigations. The complete title of this article is "Erster Zwischenbericht über die Ergebnisse der Strukturuntersuchung an Selengleichrichtern". A copy of Dr. Brill's article was obtained and brought to this country, and I have been told both by Mr. Snyder and by Mr. G. D. Edwards of our Bell Laboratories' liaison group that the article is probably now in the intelligence archives under your supervision.

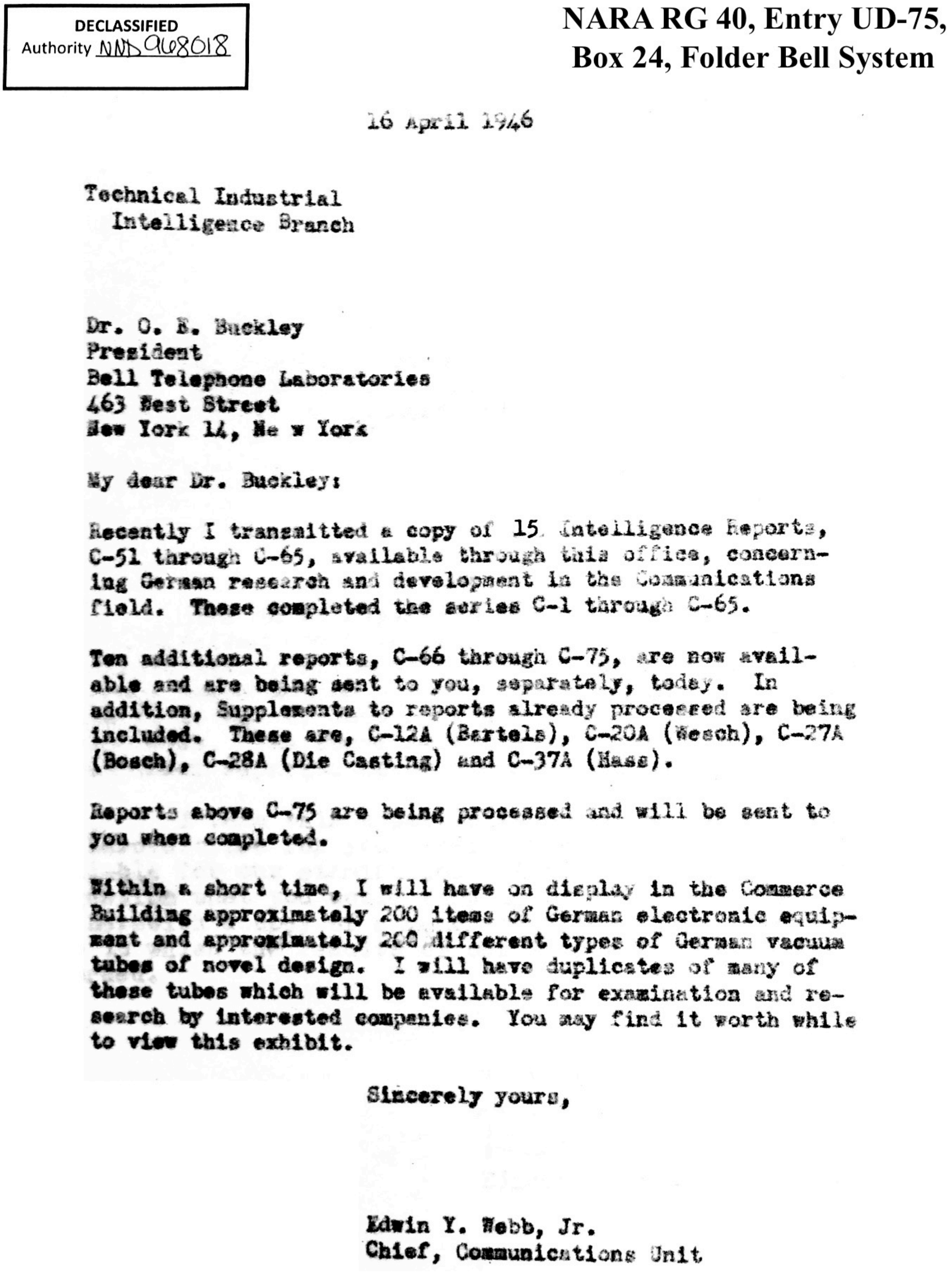
Please help us to locate this item. Can it be sent to us on loan, or should we ask for a photocopy?

Very truly yours,

John N. Shive

JOHN N. SHIVE
Member of the Technical Staff

Figure B.276: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND 968018

NARA RG 40, Entry UD-75,
Box 24, Folder Bell System

16 April 1946

Technical Industrial
Intelligence Branch

Dr. O. E. Buckley
President
Bell Telephone Laboratories
463 West Street
New York 14, New York

My dear Dr. Buckley:

Recently I transmitted a copy of 15 Intelligence Reports, C-51 through C-65, available through this office, concerning German research and development in the Communications field. These completed the series C-1 through C-65.

Ten additional reports, C-66 through C-75, are now available and are being sent to you, separately, today. In addition, Supplements to reports already processed are being included. These are, C-12A (Bartels), C-20A (Wesch), C-27A (Bosch), C-28A (Die Casting) and C-37A (Hass).

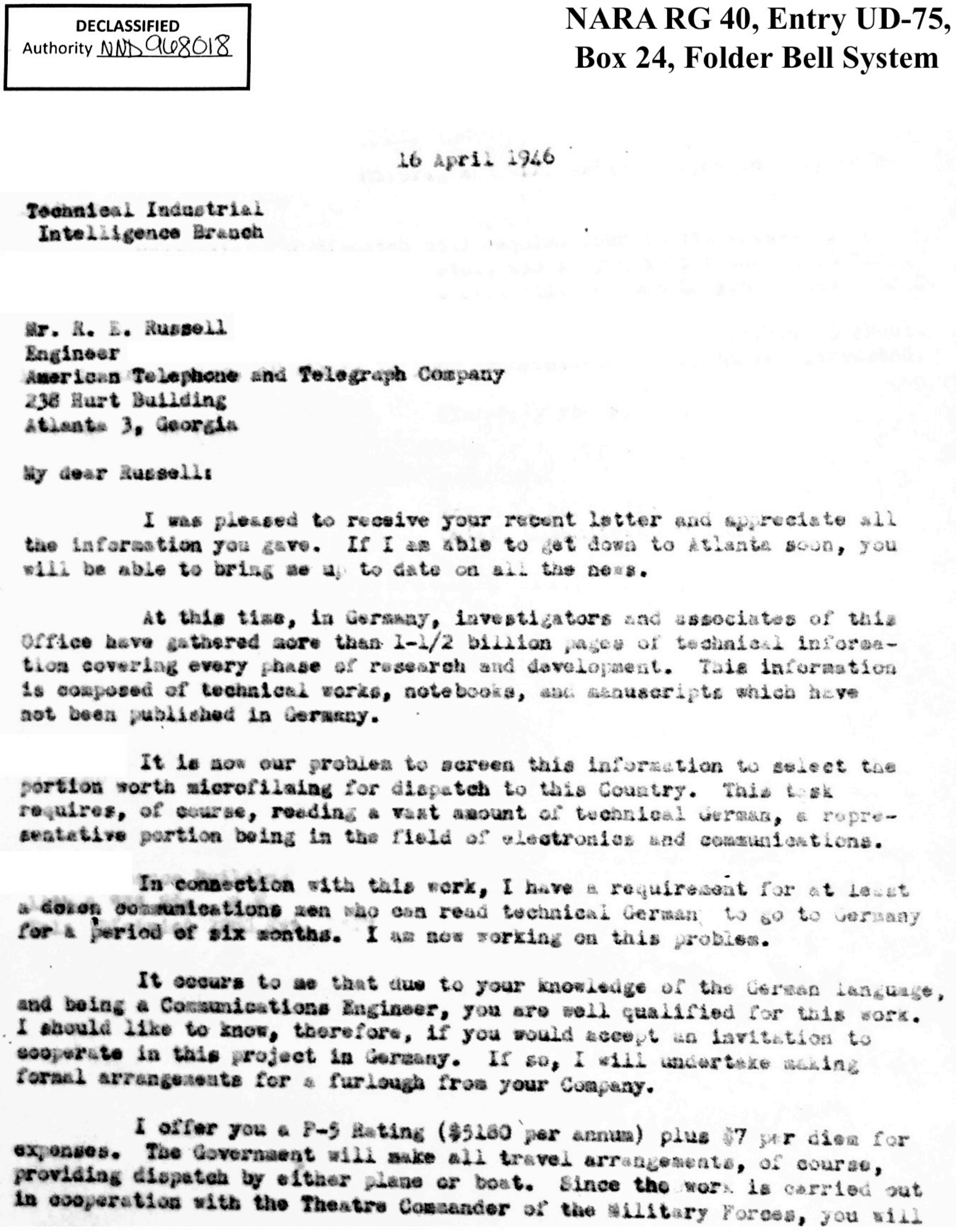
Reports above C-75 are being processed and will be sent to you when completed.

Within a short time, I will have on display in the Commerce Building approximately 200 items of German electronic equipment and approximately 200 different types of German vacuum tubes of novel design. I will have duplicates of many of these tubes which will be available for examination and research by interested companies. You may find it worth while to view this exhibit.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit

Figure B.277: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

NARA RG 40, Entry UD-75,
Box 24, Folder Bell System

16 April 1946

Technical Industrial
Intelligence Branch

Mr. R. E. Russell
Engineer
American Telephone and Telegraph Company
238 Hurt Building
Atlanta 3, Georgia

My dear Russell:

I was pleased to receive your recent letter and appreciate all the information you gave. If I am able to get down to Atlanta soon, you will be able to bring me up to date on all the news.

At this time, in Germany, investigators and associates of this Office have gathered more than 1-1/2 billion pages of technical information covering every phase of research and development. This information is composed of technical works, notebooks, and manuscripts which have not been published in Germany.

It is now our problem to screen this information to select the portion worth microfilming for dispatch to this Country. This task requires, of course, reading a vast amount of technical German, a representative portion being in the field of electronics and communications.

In connection with this work, I have a requirement for at least a dozen communications men who can read technical German to go to Germany for a period of six months. I am now working on this problem.

It occurs to me that due to your knowledge of the German language, and being a Communications Engineer, you are well qualified for this work. I should like to know, therefore, if you would accept an invitation to cooperate in this project in Germany. If so, I will undertake making formal arrangements for a furlough from your Company.

I offer you a P-5 Rating ($5180 per annum) plus $7 per diem for expenses. The Government will make all travel arrangements, of course, providing dispatch by either plane or boat. Since the work is carried out in cooperation with the Theatre Commander of the Military Forces, you will

Figure B.278: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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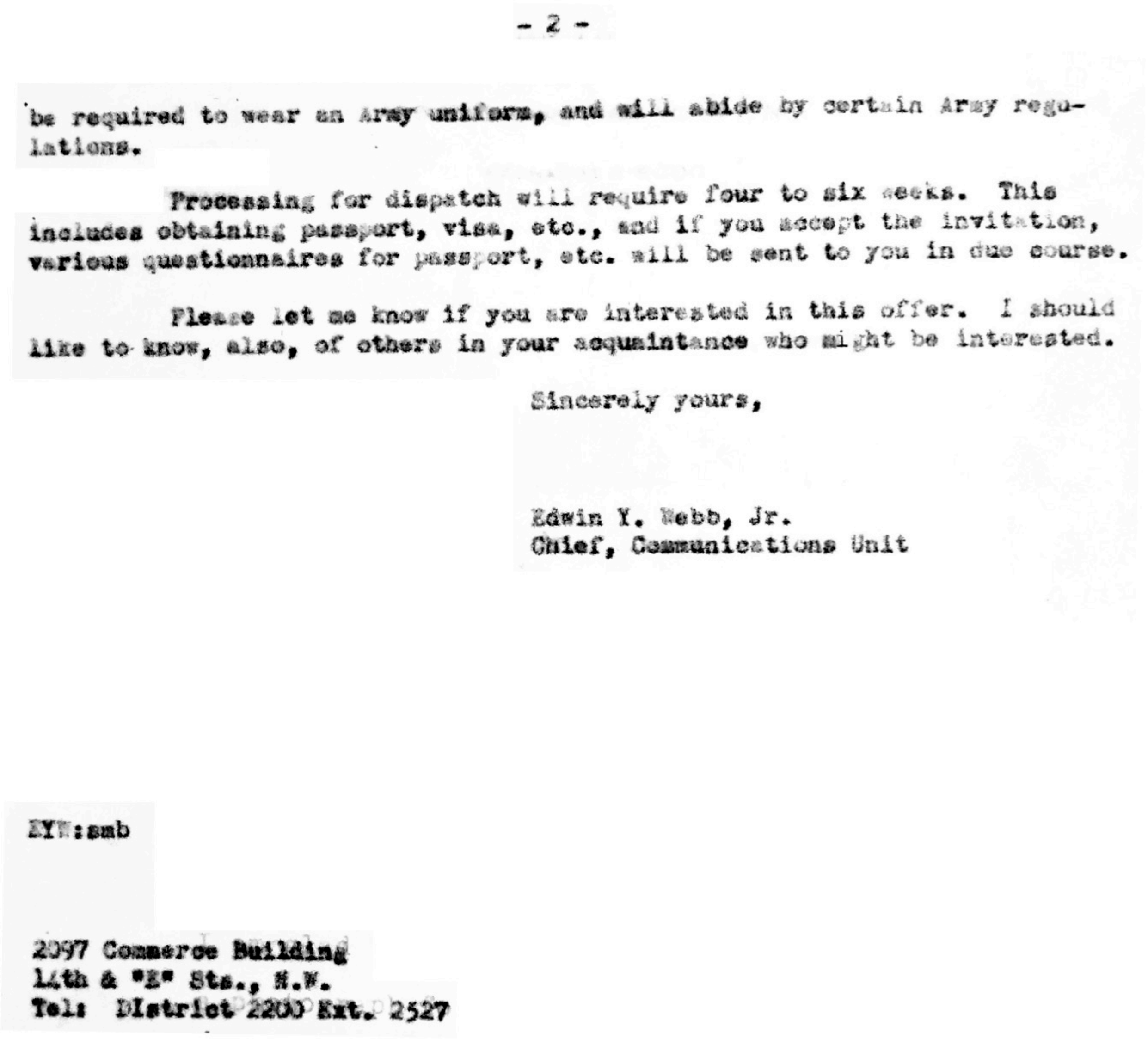
Box 24, Folder Bell System



- 2 -

be required to wear an Army uniform, and will abide by certain Army regulations.

Processing for dispatch will require four to six weeks. This includes obtaining passport, visa, etc., and if you accept the invitation, various questionnaires for passport, etc. will be sent to you in due course.

Please let me know if you are interested in this offer. I should like to know, also, of others in your acquaintance who might be interested.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit

EYW:smb

2097 Commerce Building
14th & "E" Sts., N.W.
Tel: District 2200 Ext. 2527

Figure B.279: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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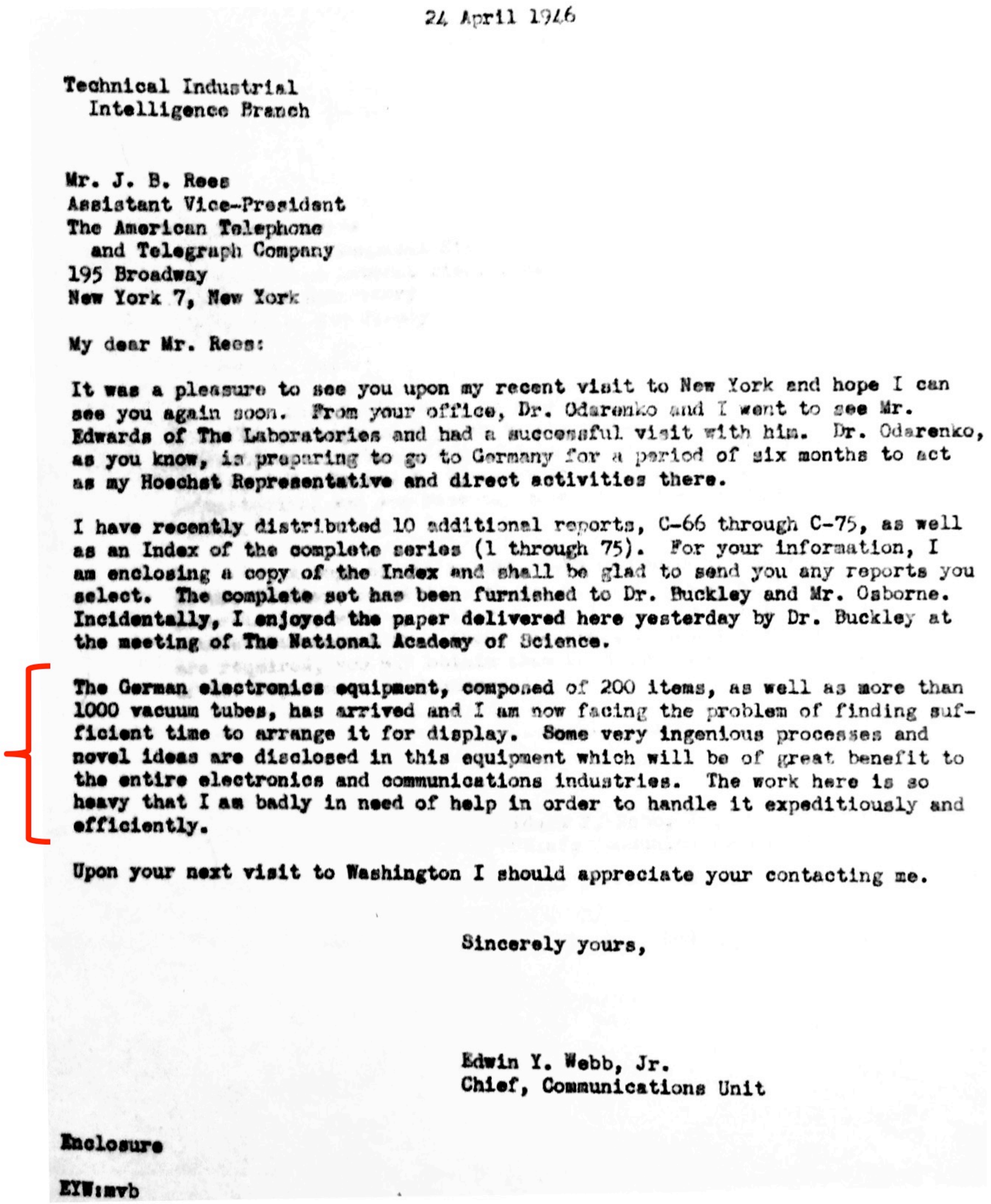
**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**



24 April 1946

Technical Industrial
Intelligence Branch

Mr. J. B. Rees
Assistant Vice-President
The American Telephone
and Telegraph Company
195 Broadway
New York 7, New York

My dear Mr. Rees:

It was a pleasure to see you upon my recent visit to New York and hope I can see you again soon. From your office, Dr. Odarenko and I went to see Mr. Edwards of The Laboratories and had a successful visit with him. Dr. Odarenko, as you know, is preparing to go to Germany for a period of six months to act as my Hoechst Representative and direct activities there.

I have recently distributed 10 additional reports, C-66 through C-75, as well as an Index of the complete series (1 through 75). For your information, I am enclosing a copy of the Index and shall be glad to send you any reports you select. The complete set has been furnished to Dr. Buckley and Mr. Osborne. Incidentally, I enjoyed the paper delivered here yesterday by Dr. Buckley at the meeting of The National Academy of Science.

The German electronics equipment, composed of 200 items, as well as more than 1000 vacuum tubes, has arrived and I am now facing the problem of finding sufficient time to arrange it for display. Some very ingenious processes and novel ideas are disclosed in this equipment which will be of great benefit to the entire electronics and communications industries. The work here is so heavy that I am badly in need of help in order to handle it expeditiously and efficiently.

Upon your next visit to Washington I should appreciate your contacting me.

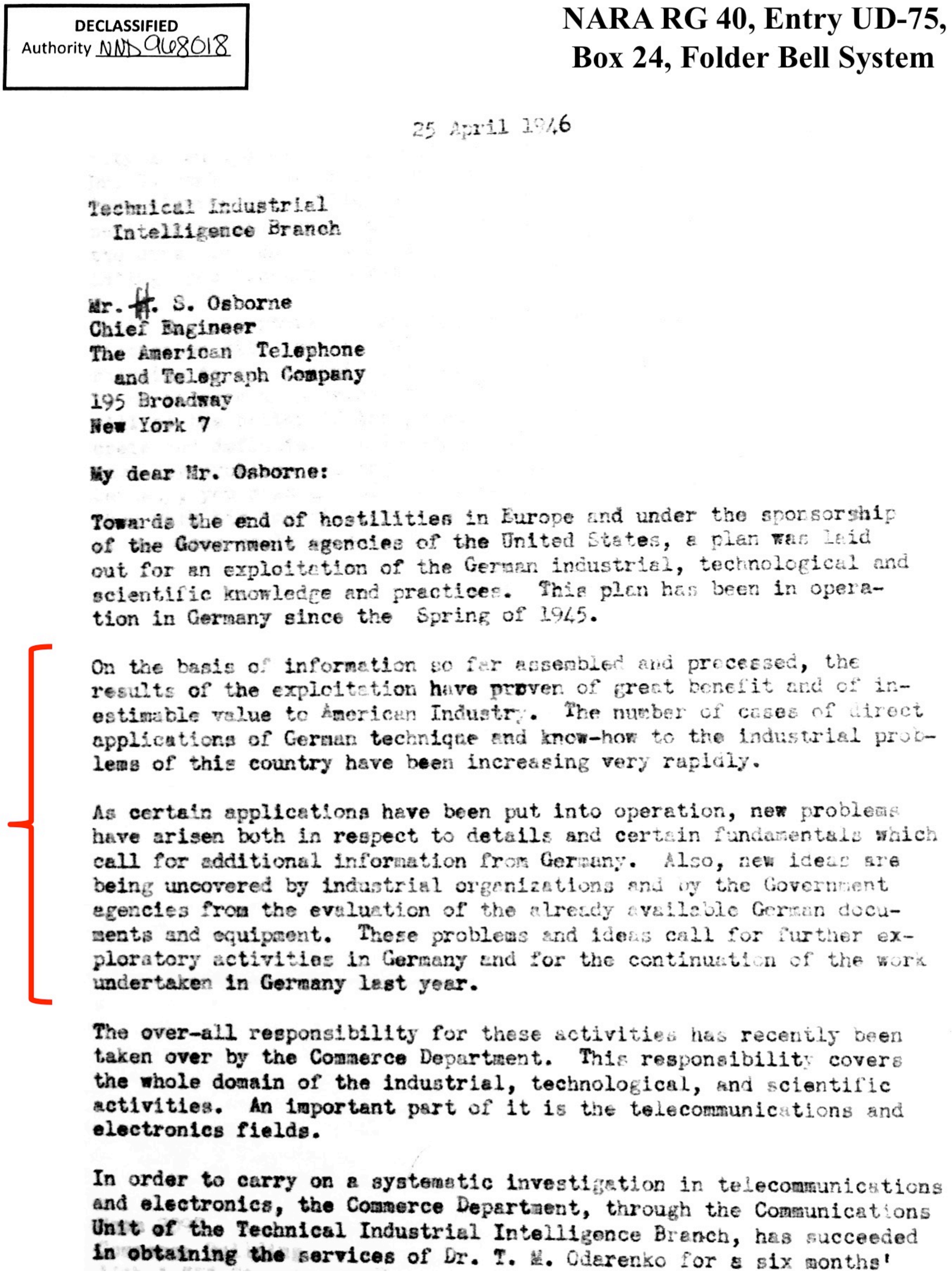
Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit

Enclosure

EYW:mvb

Figure B.280: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

25 April 1946

Technical Industrial
Intelligence Branch

Mr. H. S. Osborne
Chief Engineer
The American Telephone
and Telegraph Company
195 Broadway
New York 7

My dear Mr. Osborne:

Towards the end of hostilities in Europe and under the sponsorship of the Government agencies of the United States, a plan was laid out for an exploitation of the German industrial, technological and scientific knowledge and practices. This plan has been in operation in Germany since the Spring of 1945.

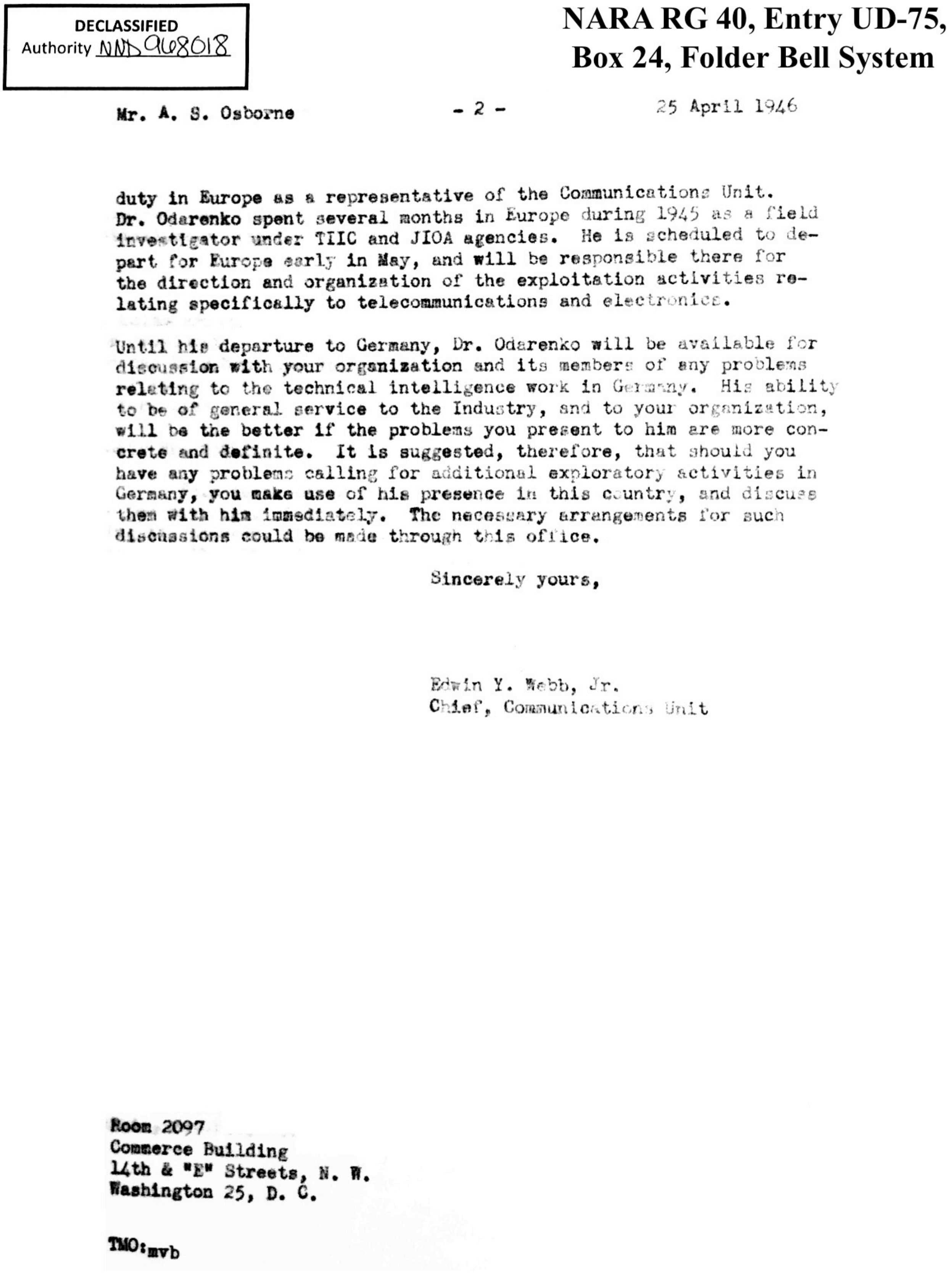
On the basis of information so far assembled and processed, the results of the exploitation have proven of great benefit and of inestimable value to American Industry. The number of cases of direct applications of German technique and know-how to the industrial problems of this country have been increasing very rapidly.

As certain applications have been put into operation, new problems have arisen both in respect to details and certain fundamentals which call for additional information from Germany. Also, new ideas are being uncovered by industrial organizations and by the Government agencies from the evaluation of the already available German documents and equipment. These problems and ideas call for further exploratory activities in Germany and for the continuation of the work undertaken in Germany last year.

The over-all responsibility for these activities has recently been taken over by the Commerce Department. This responsibility covers the whole domain of the industrial, technological, and scientific activities. An important part of it is the telecommunications and electronics fields.

In order to carry on a systematic investigation in telecommunications and electronics, the Commerce Department, through the Communications Unit of the Technical Industrial Intelligence Branch, has succeeded in obtaining the services of Dr. T. M. Odarenko for a six months'

Figure B.281: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

Mr. A. S. Osborne - 2 - 25 April 1946

duty in Europe as a representative of the Communications Unit. Dr. Odarenko spent several months in Europe during 1945 as a field investigator under TIIC and JIOA agencies. He is scheduled to depart for Europe early in May, and will be responsible there for the direction and organization of the exploitation activities relating specifically to telecommunications and electronics.

Until his departure to Germany, Dr. Odarenko will be available for discussion with your organization and its members of any problems relating to the technical intelligence work in Germany. His ability to be of general service to the Industry, and to your organization, will be the better if the problems you present to him are more concrete and definite. It is suggested, therefore, that should you have any problems calling for additional exploratory activities in Germany, you make use of his presence in this country, and discuss them with him immediately. The necessary arrangements for such discussions could be made through this office.

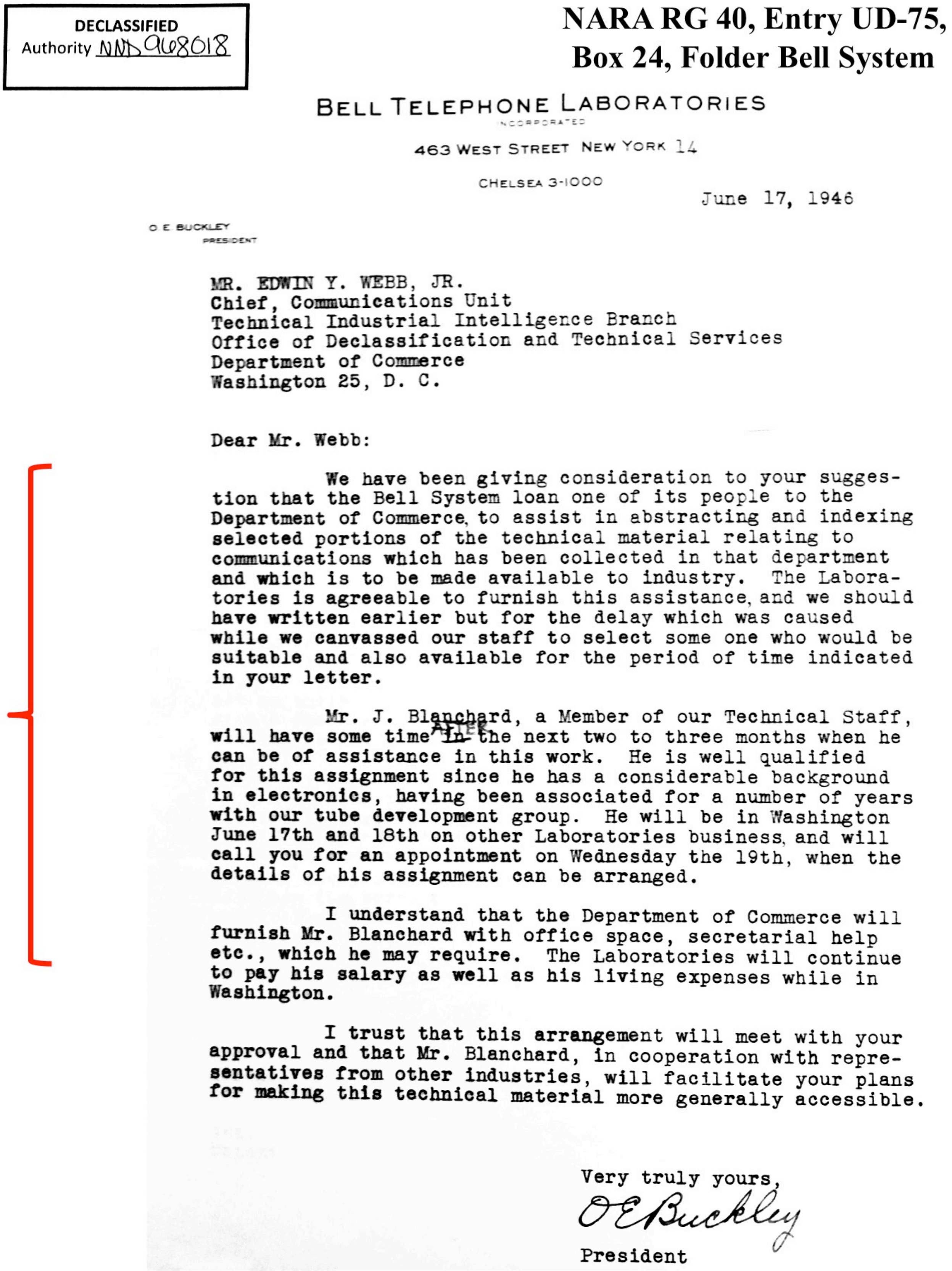
Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Communications Unit

Room 2097
Commerce Building
14th & "E" Streets, N. W.
Washington 25, D. C.

TMO:mvb

Figure B.282: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

BELL TELEPHONE LABORATORIES
INCORPORATED
463 WEST STREET NEW YORK 14
CHELSEA 3-1000

June 17, 1946

O. E. BUCKLEY
PRESIDENT

MR. EDWIN Y. WEBB, JR.
Chief, Communications Unit
Technical Industrial Intelligence Branch
Office of Declassification and Technical Services
Department of Commerce
Washington 25, D. C.

Dear Mr. Webb:

We have been giving consideration to your suggestion that the Bell System loan one of its people to the Department of Commerce, to assist in abstracting and indexing selected portions of the technical material relating to communications which has been collected in that department and which is to be made available to industry. The Laboratories is agreeable to furnish this assistance, and we should have written earlier but for the delay which was caused while we canvassed our staff to select some one who would be suitable and also available for the period of time indicated in your letter.

Mr. J. Blanchard, a Member of our Technical Staff, will have some time ~~in~~ After the next two to three months when he can be of assistance in this work. He is well qualified for this assignment since he has a considerable background in electronics, having been associated for a number of years with our tube development group. He will be in Washington June 17th and 18th on other Laboratories business, and will call you for an appointment on Wednesday the 19th, when the details of his assignment can be arranged.

I understand that the Department of Commerce will furnish Mr. Blanchard with office space, secretarial help etc., which he may require. The Laboratories will continue to pay his salary as well as his living expenses while in Washington.

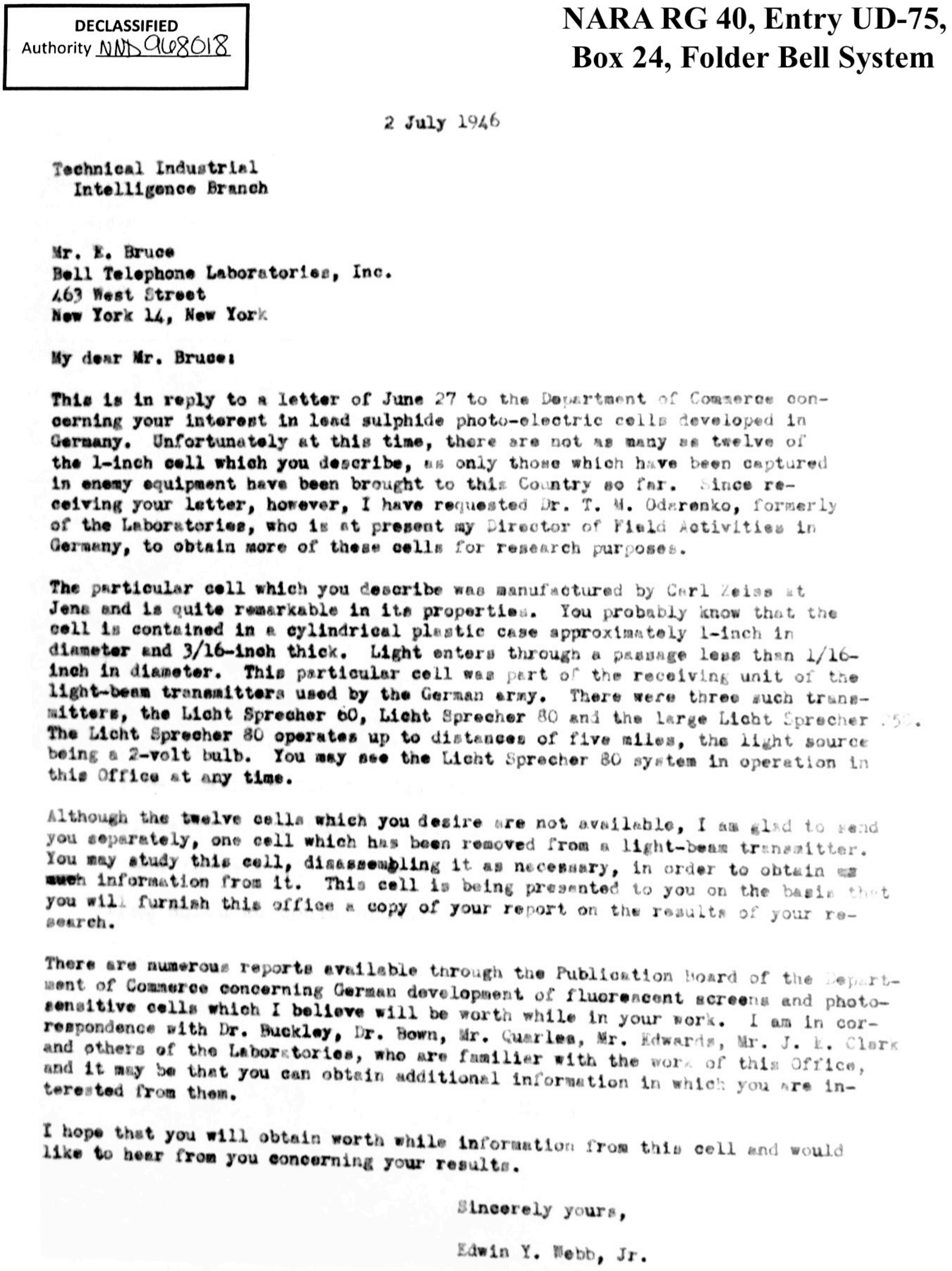
I trust that this arrangement will meet with your approval and that Mr. Blanchard, in cooperation with representatives from other industries, will facilitate your plans for making this technical material more generally accessible.

Very truly yours,

O E Buckley

President

Figure B.283: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

2 July 1946

Technical Industrial
Intelligence Branch

Mr. E. Bruce
Bell Telephone Laboratories, Inc.
463 West Street
New York 14, New York

My dear Mr. Bruce:

This is in reply to a letter of June 27 to the Department of Commerce concerning your interest in lead sulphide photo-electric cells developed in Germany. Unfortunately at this time, there are not as many as twelve of the 1-inch cell which you describe, as only those which have been captured in enemy equipment have been brought to this Country so far. Since receiving your letter, however, I have requested Dr. T. M. Odarenko, formerly of the Laboratories, who is at present my Director of Field Activities in Germany, to obtain more of these cells for research purposes.

The particular cell which you describe was manufactured by Carl Zeiss at Jena and is quite remarkable in its properties. You probably know that the cell is contained in a cylindrical plastic case approximately 1-inch in diameter and 3/16-inch thick. Light enters through a passage less than 1/16-inch in diameter. This particular cell was part of the receiving unit of the light-beam transmitters used by the German army. There were three such transmitters, the Licht Sprecher 60, Licht Sprecher 80 and the large Licht Sprecher 250. The Licht Sprecher 80 operates up to distances of five miles, the light source being a 2-volt bulb. You may see the Licht Sprecher 80 system in operation in this Office at any time.

Although the twelve cells which you desire are not available, I am glad to send you separately, one cell which has been removed from a light-beam transmitter. You may study this cell, disassembling it as necessary, in order to obtain as much information from it. This cell is being presented to you on the basis that you will furnish this office a copy of your report on the results of your research.

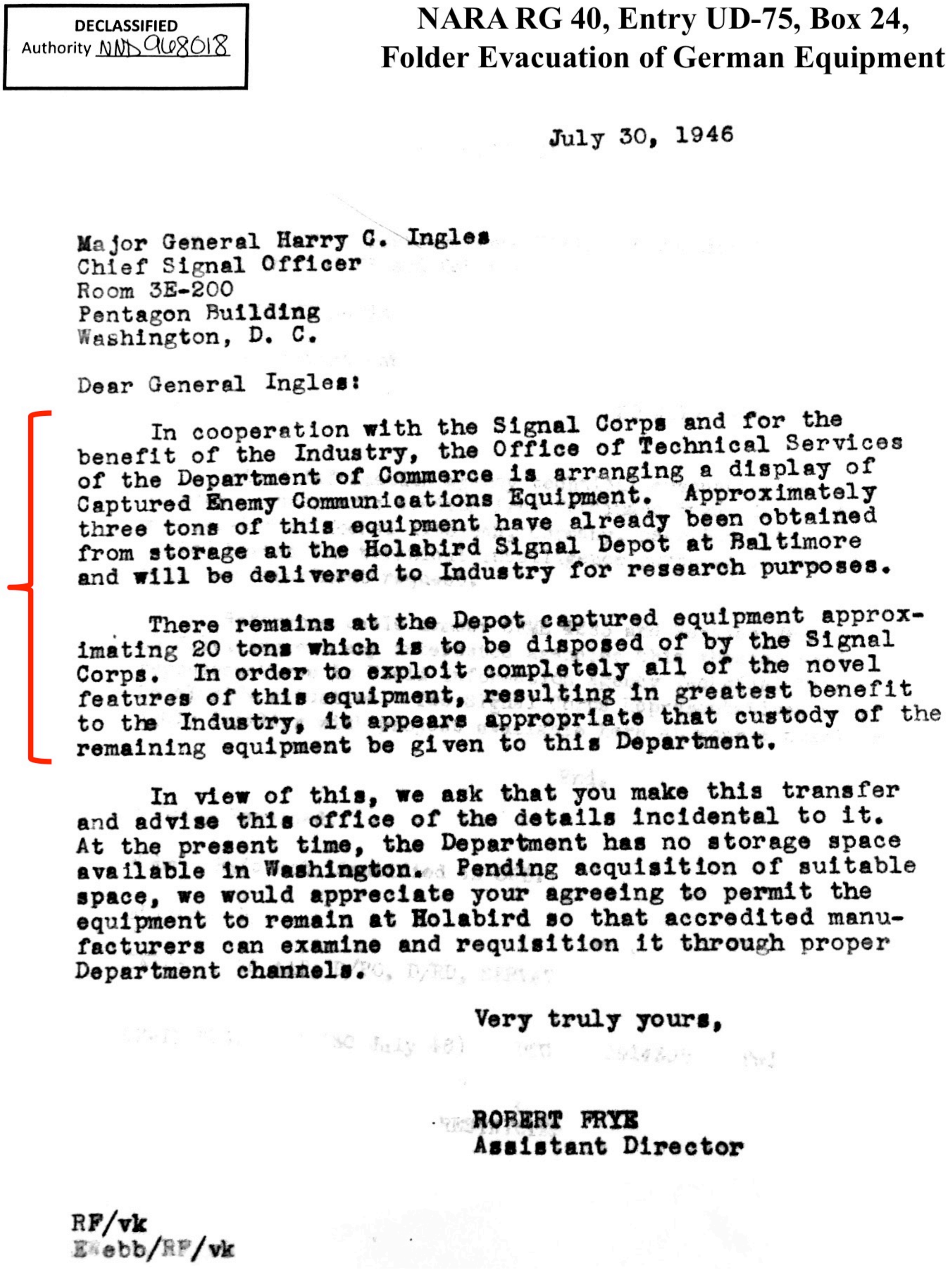
There are numerous reports available through the Publication Board of the Department of Commerce concerning German development of fluorescent screens and photo-sensitive cells which I believe will be worth while in your work. I am in correspondence with Dr. Buckley, Dr. Bown, Mr. Quarles, Mr. Edwards, Mr. J. E. Clark and others of the Laboratories, who are familiar with the work of this Office, and it may be that you can obtain additional information in which you are interested from them.

I hope that you will obtain worth while information from this cell and would like to hear from you concerning your results.

Sincerely yours,

Edwin Y. Webb, Jr.

Figure B.284: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24,
Folder Evacuation of German Equipment

July 30, 1946

Major General Harry C. Ingles
Chief Signal Officer
Room 3E-200
Pentagon Building
Washington, D. C.

Dear General Ingles:

In cooperation with the Signal Corps and for the benefit of the Industry, the Office of Technical Services of the Department of Commerce is arranging a display of Captured Enemy Communications Equipment. Approximately three tons of this equipment have already been obtained from storage at the Holabird Signal Depot at Baltimore and will be delivered to Industry for research purposes.

There remains at the Depot captured equipment approximating 20 tons which is to be disposed of by the Signal Corps. In order to exploit completely all of the novel features of this equipment, resulting in greatest benefit to the Industry, it appears appropriate that custody of the remaining equipment be given to this Department.

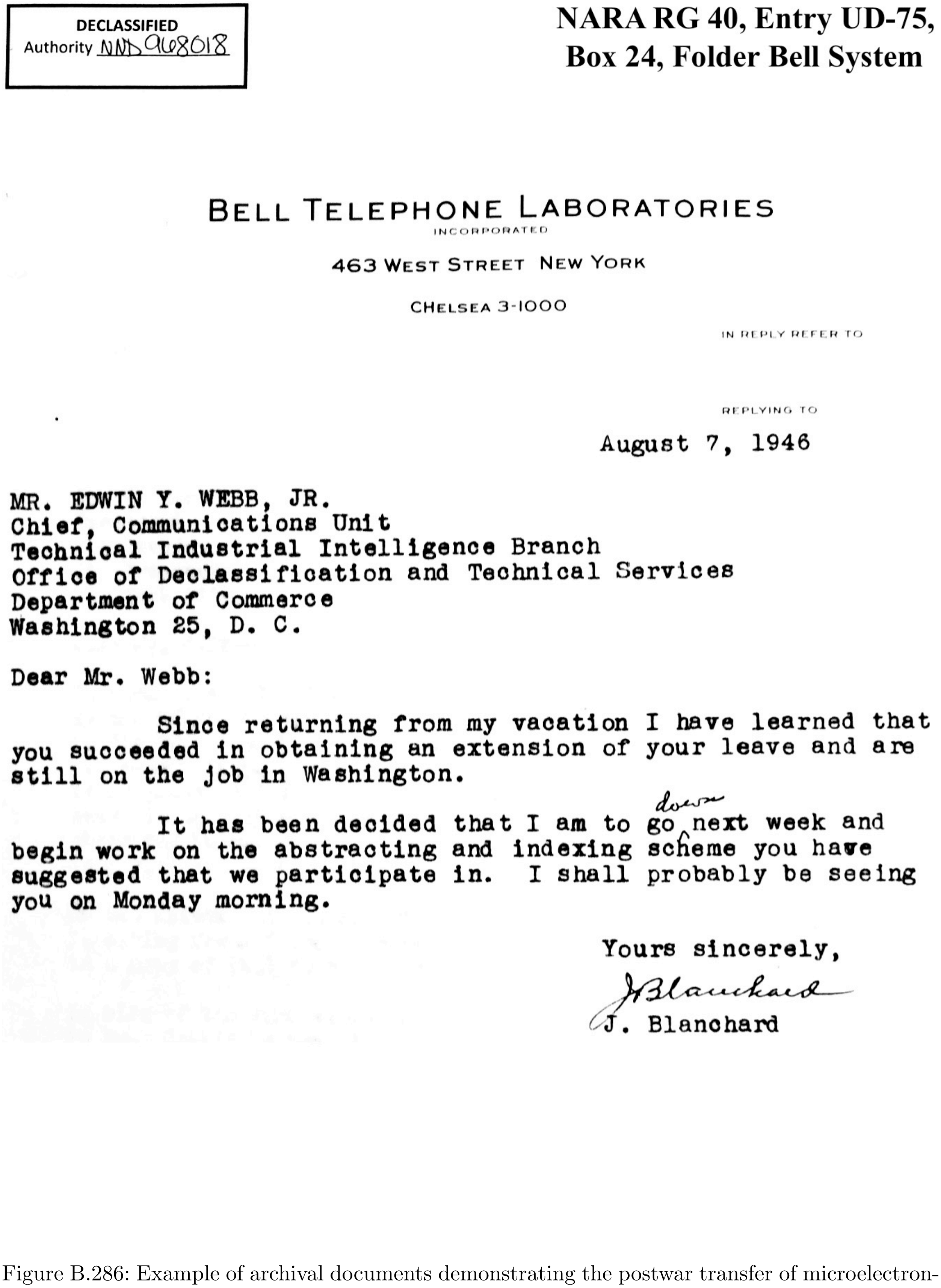
In view of this, we ask that you make this transfer and advise this office of the details incidental to it. At the present time, the Department has no storage space available in Washington. Pending acquisition of suitable space, we would appreciate your agreeing to permit the equipment to remain at Holabird so that accredited manufacturers can examine and requisition it through proper Department channels.

Very truly yours,

ROBERT FRYE
Assistant Director

RF/vk
E.ebb/RF/vk

Figure B.285: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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NARA RG 40, Entry UD-75,
Box 24, Folder Bell System

BELL TELEPHONE LABORATORIES
INCORPORATED

463 WEST STREET NEW YORK

CHELSEA 3-1000

IN REPLY REFER TO

REPLYING TO

August 7, 1946

MR. EDWIN Y. WEBB, JR.
Chief, Communications Unit
Technical Industrial Intelligence Branch
Office of Declassification and Technical Services
Department of Commerce
Washington 25, D. C.

Dear Mr. Webb:

Since returning from my vacation I have learned that you succeeded in obtaining an extension of your leave and are still on the job in Washington.

It has been decided that I am to go down next week and begin work on the abstracting and indexing scheme you have suggested that we participate in. I shall probably be seeing you on Monday morning.

Yours sincerely,

JBlanchard

J. Blanchard

Figure B.286: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

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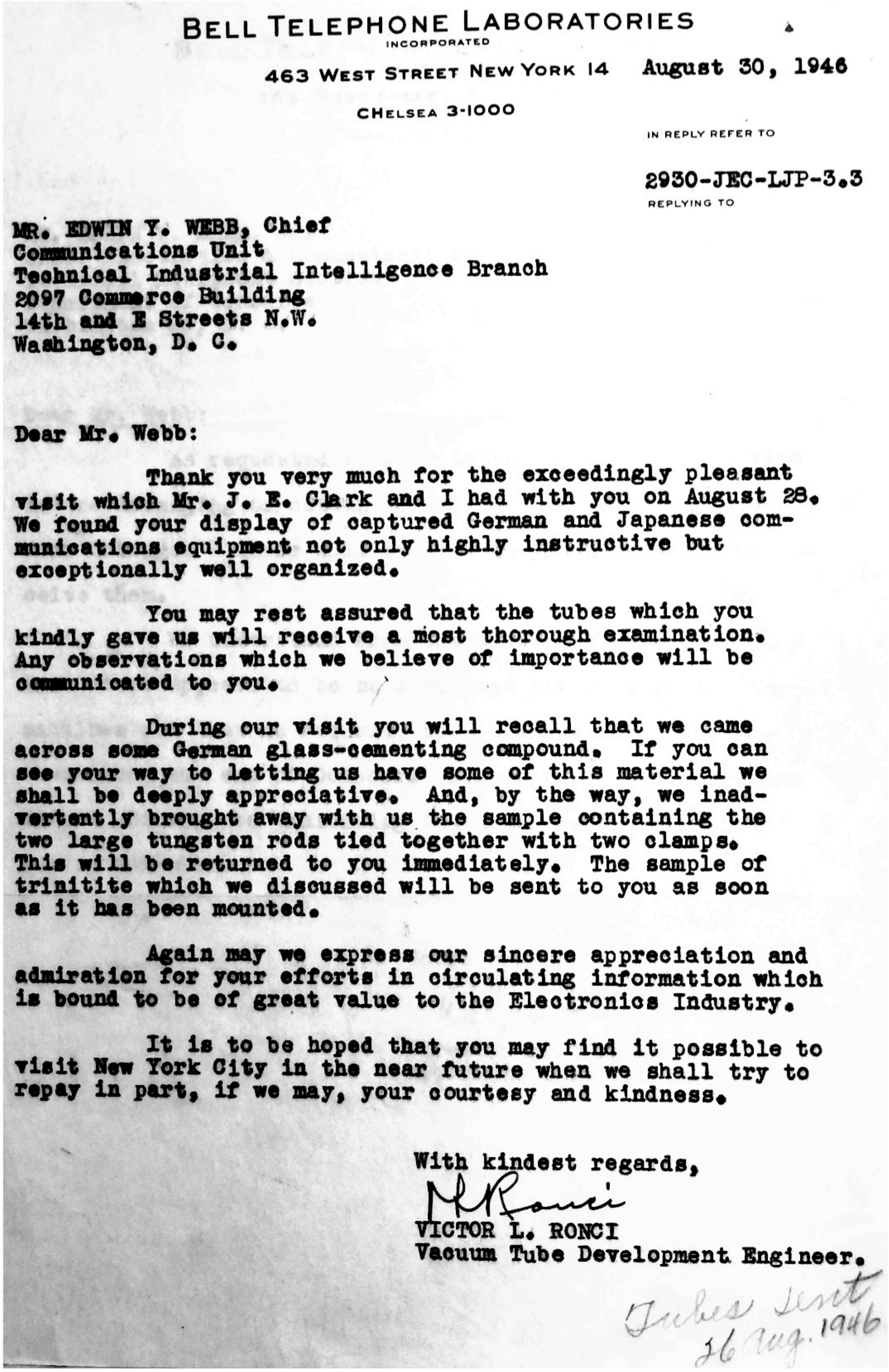
Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**



BELL TELEPHONE LABORATORIES
INCORPORATED
463 WEST STREET NEW YORK 14
CHELSEA 3-1000

August 30, 1946

IN REPLY REFER TO
2930-JEC-LJP-3.3
REPLYING TO

MR. EDWIN Y. WEBB, Chief
Communications Unit
Technical Industrial Intelligence Branch
2097 Commerce Building
14th and E Streets N.W.
Washington, D. C.

Dear Mr. Webb:

Thank you very much for the exceedingly pleasant visit which Mr. J. E. Clark and I had with you on August 28. We found your display of captured German and Japanese communications equipment not only highly instructive but exceptionally well organized.

You may rest assured that the tubes which you kindly gave us will receive a most thorough examination. Any observations which we believe of importance will be communicated to you.

During our visit you will recall that we came across some German glass-cementing compound. If you can see your way to letting us have some of this material we shall be deeply appreciative. And, by the way, we inadvertently brought away with us the sample containing the two large tungsten rods tied together with two clamps. This will be returned to you immediately. The sample of trinitite which we discussed will be sent to you as soon as it has been mounted.

Again may we express our sincere appreciation and admiration for your efforts in circulating information which is bound to be of great value to the Electronics Industry.

It is to be hoped that you may find it possible to visit New York City in the near future when we shall try to repay in part, if we may, your courtesy and kindness.

With kindest regards,

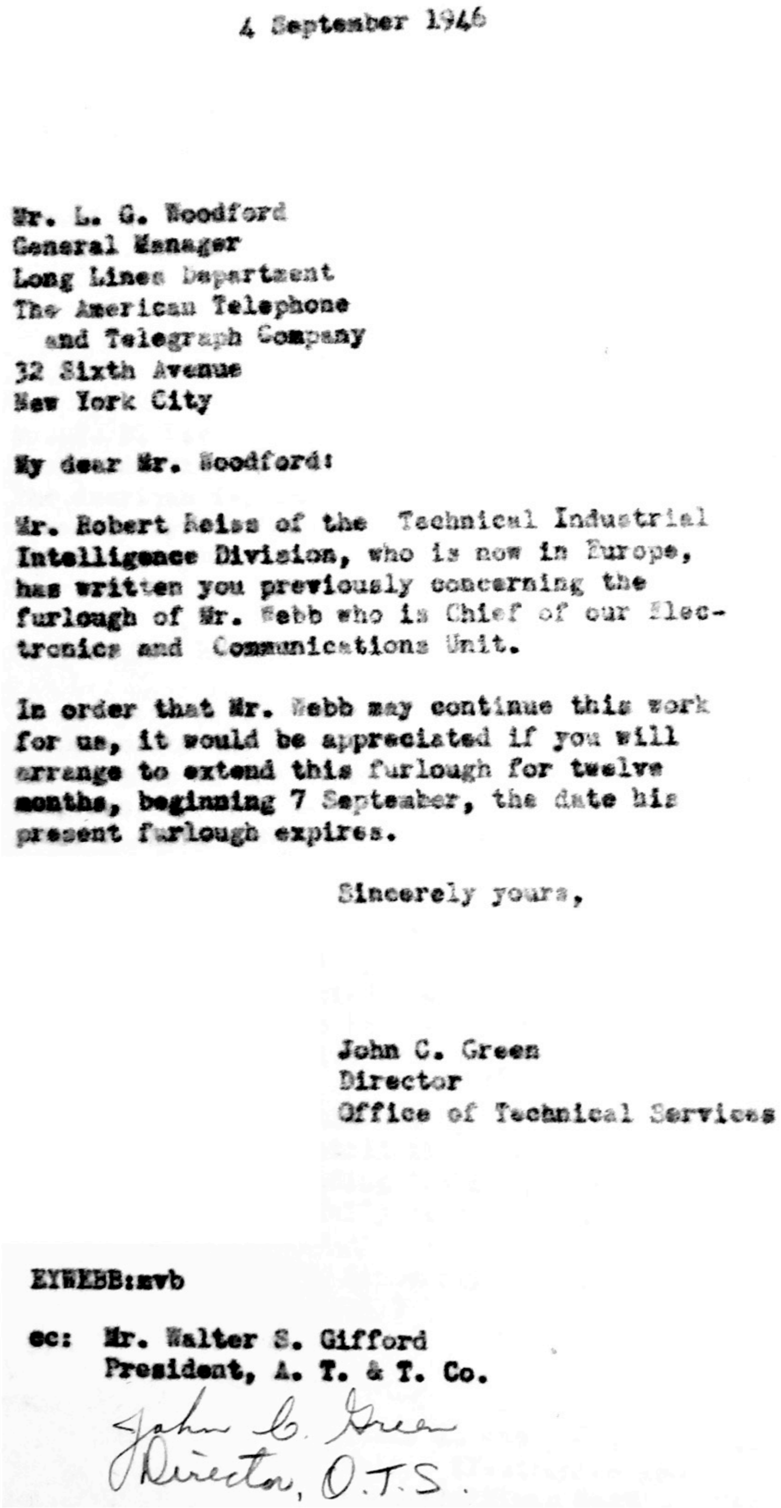
VLRonci
VICTOR L. RONCI
Vacuum Tube Development Engineer.

Tubes sent
26 Aug. 1946

Figure B.287: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75,
Box 24, Folder Bell System



4 September 1946

Mr. L. G. Woodford
General Manager
Long Lines Department
The American Telephone
and Telegraph Company
32 Sixth Avenue
New York City

My dear Mr. Woodford:

Mr. Robert Reiss of the Technical Industrial Intelligence Division, who is now in Europe, has written you previously concerning the furlough of Mr. Webb who is Chief of our Electronics and Communications Unit.

In order that Mr. Webb may continue this work for us, it would be appreciated if you will arrange to extend this furlough for twelve months, beginning 7 September, the date his present furlough expires.

Sincerely yours,

John C. Green
Director
Office of Technical Services

EYWEBB:mvb

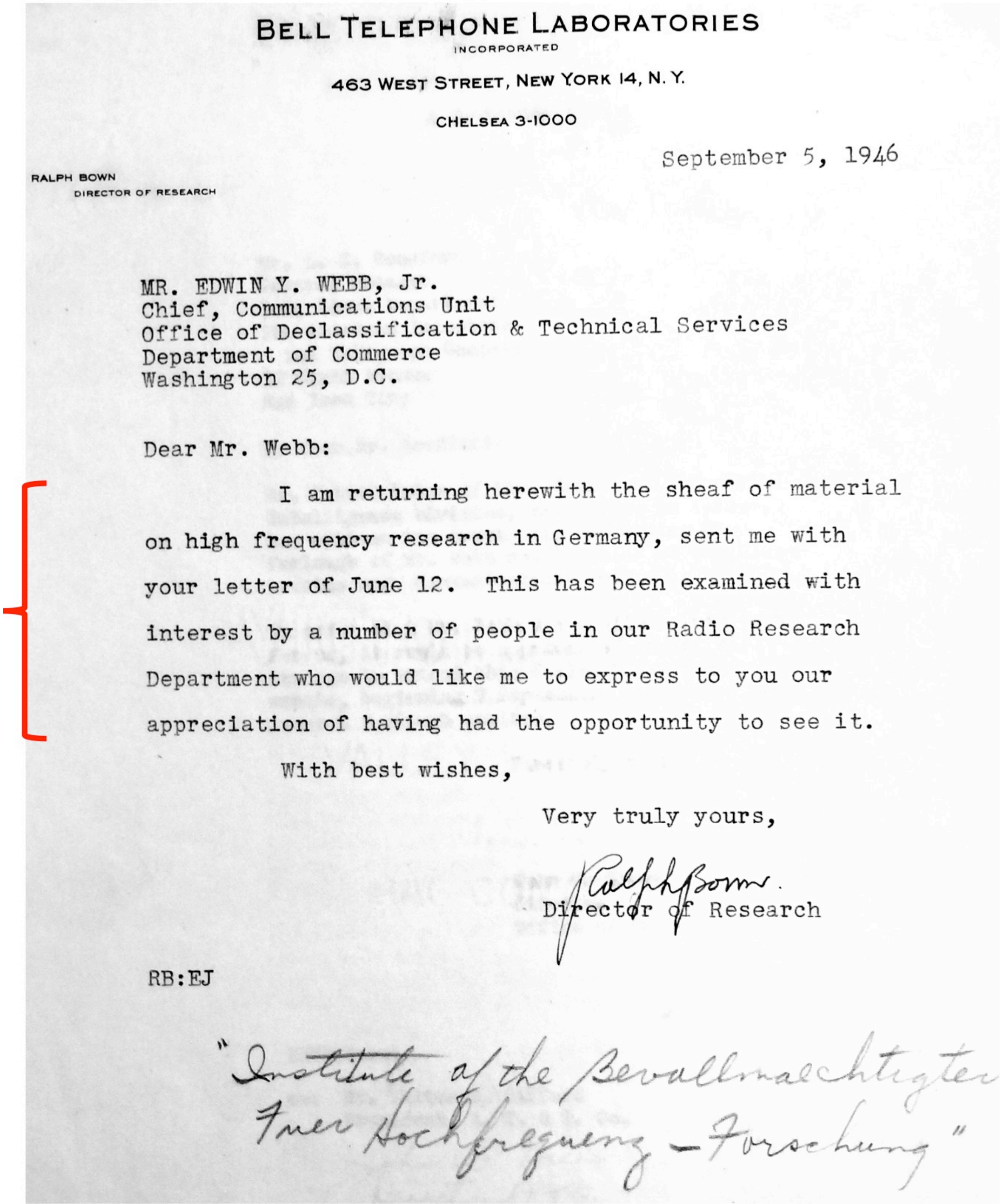
cc: Mr. Walter S. Gifford
President, A. T. & T. Co.

John C. Green
Director, O.T.S.

Figure B.288: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System



BELL TELEPHONE LABORATORIES
INCORPORATED
463 WEST STREET, NEW YORK 14, N. Y.
CHELSEA 3-1000

RALPH BOWN
DIRECTOR OF RESEARCH

September 5, 1946

MR. EDWIN Y. WEBB, Jr.
Chief, Communications Unit
Office of Declassification & Technical Services
Department of Commerce
Washington 25, D.C.

Dear Mr. Webb:

I am returning herewith the sheaf of material on high frequency research in Germany, sent me with your letter of June 12. This has been examined with interest by a number of people in our Radio Research Department who would like me to express to you our appreciation of having had the opportunity to see it.

With best wishes,

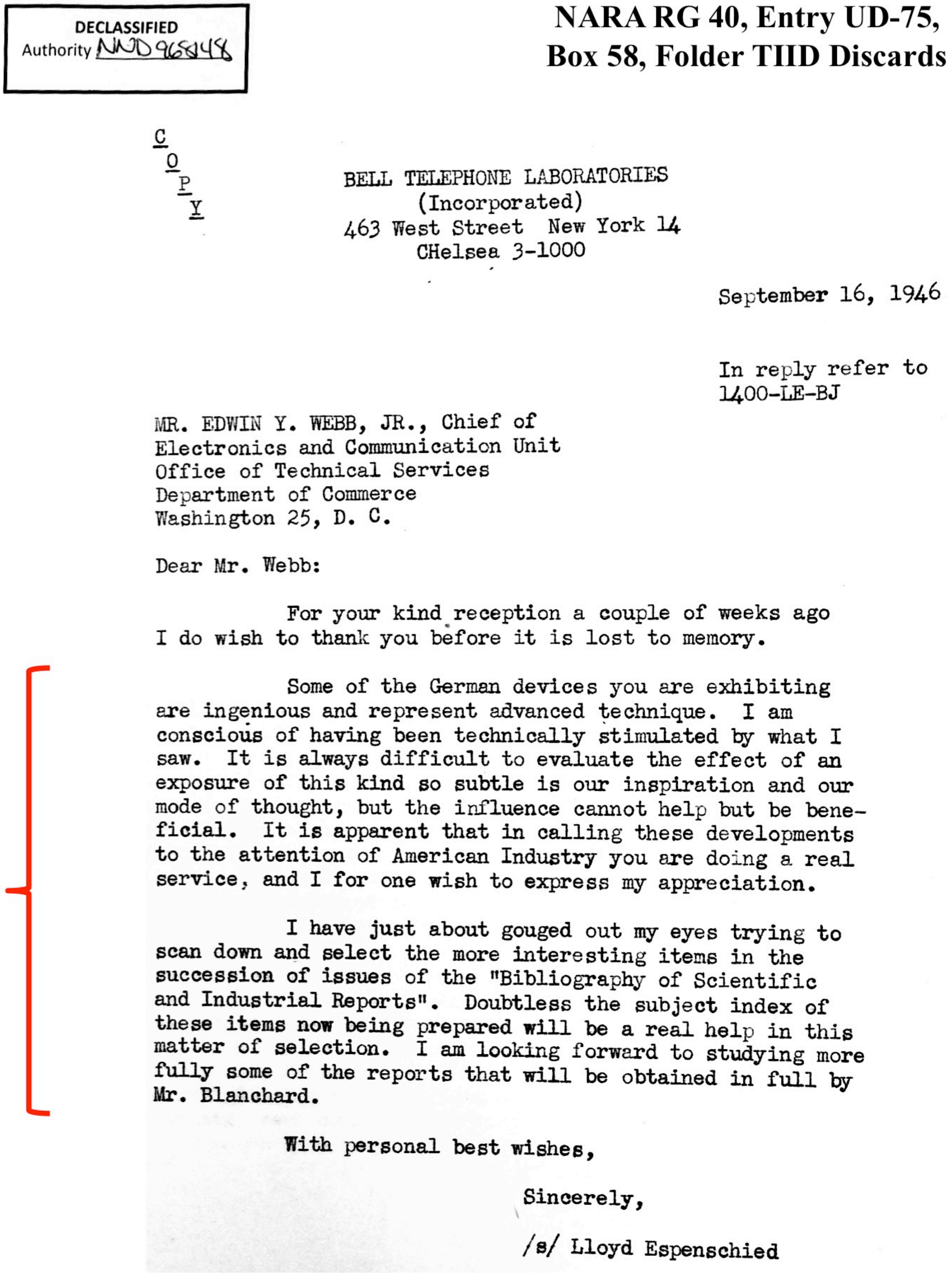
Very truly yours,

Ralph Bown.
Director of Research

RB:EJ

"~~Institute~~ of the Bevollmaechtigter Fuer Hochfrequenz-Forschung"

Figure B.289: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND 968148

**NARA RG 40, Entry UD-75,
Box 58, Folder TIID Discards**

C
O
P
Y

BELL TELEPHONE LABORATORIES
(Incorporated)
463 West Street New York 14
CHelsea 3-1000

September 16, 1946

In reply refer to
1400-LE-BJ

MR. EDWIN Y. WEBB, JR., Chief of
Electronics and Communication Unit
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Dear Mr. Webb:

For your kind reception a couple of weeks ago I do wish to thank you before it is lost to memory.

Some of the German devices you are exhibiting are ingenious and represent advanced technique. I am conscious of having been technically stimulated by what I saw. It is always difficult to evaluate the effect of an exposure of this kind so subtle is our inspiration and our mode of thought, but the influence cannot help but be beneficial. It is apparent that in calling these developments to the attention of American Industry you are doing a real service, and I for one wish to express my appreciation.

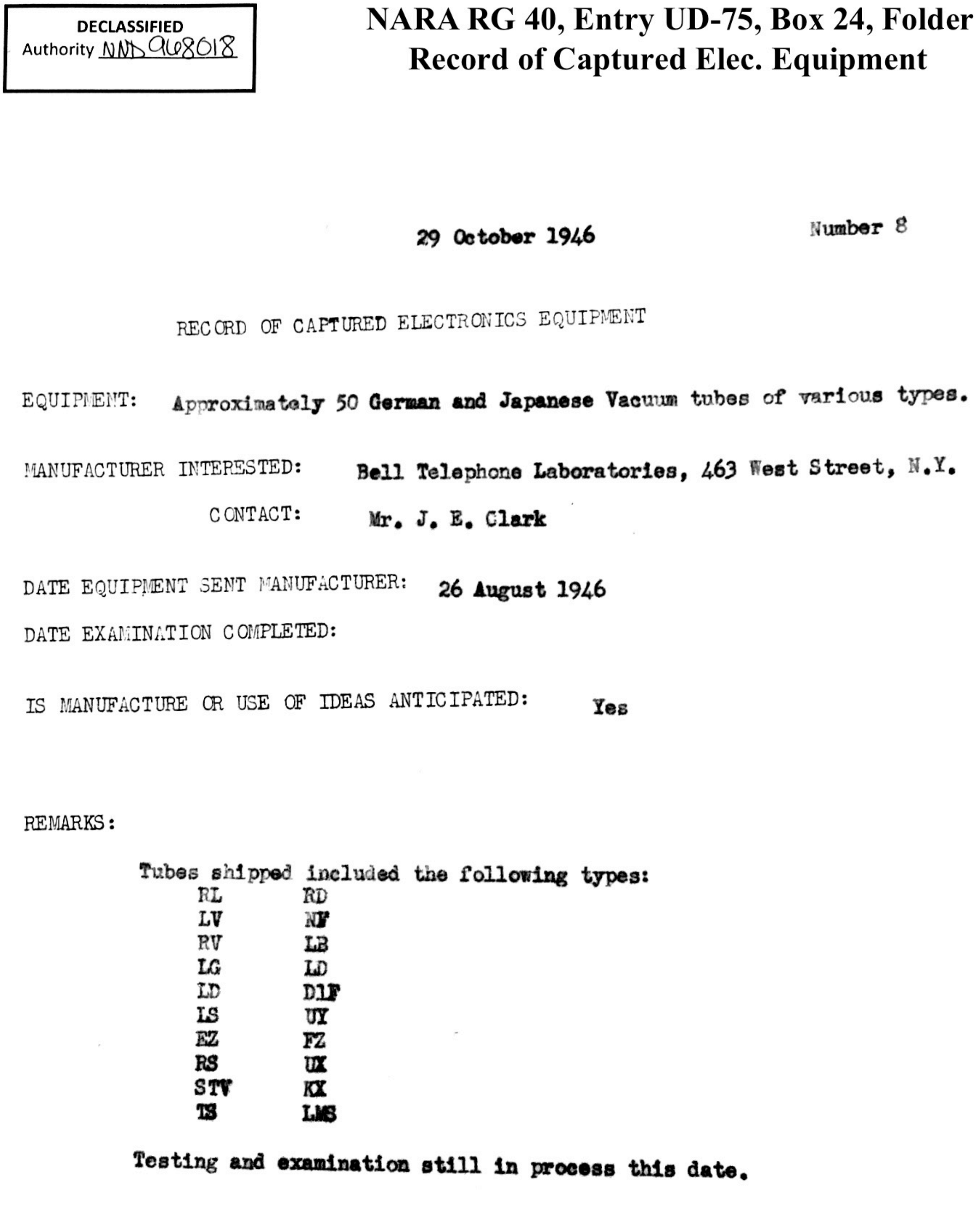
I have just about gouged out my eyes trying to scan down and select the more interesting items in the succession of issues of the "Bibliography of Scientific and Industrial Reports". Doubtless the subject index of these items now being prepared will be a real help in this matter of selection. I am looking forward to studying more fully some of the reports that will be obtained in full by Mr. Blanchard.

With personal best wishes,

Sincerely,

/s/ Lloyd Espenschied

Figure B.290: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment

29 October 1946

Number 8

RECORD OF CAPTURED ELECTRONICS EQUIPMENT

EQUIPMENT: Approximately 50 German and Japanese Vacuum tubes of various types.

MANUFACTURER INTERESTED: Bell Telephone Laboratories, 463 West Street, N.Y.

CONTACT: Mr. J. E. Clark

DATE EQUIPMENT SENT MANUFACTURER: 26 August 1946

DATE EXAMINATION COMPLETED:

IS MANUFACTURE OR USE OF IDEAS ANTICIPATED: Yes

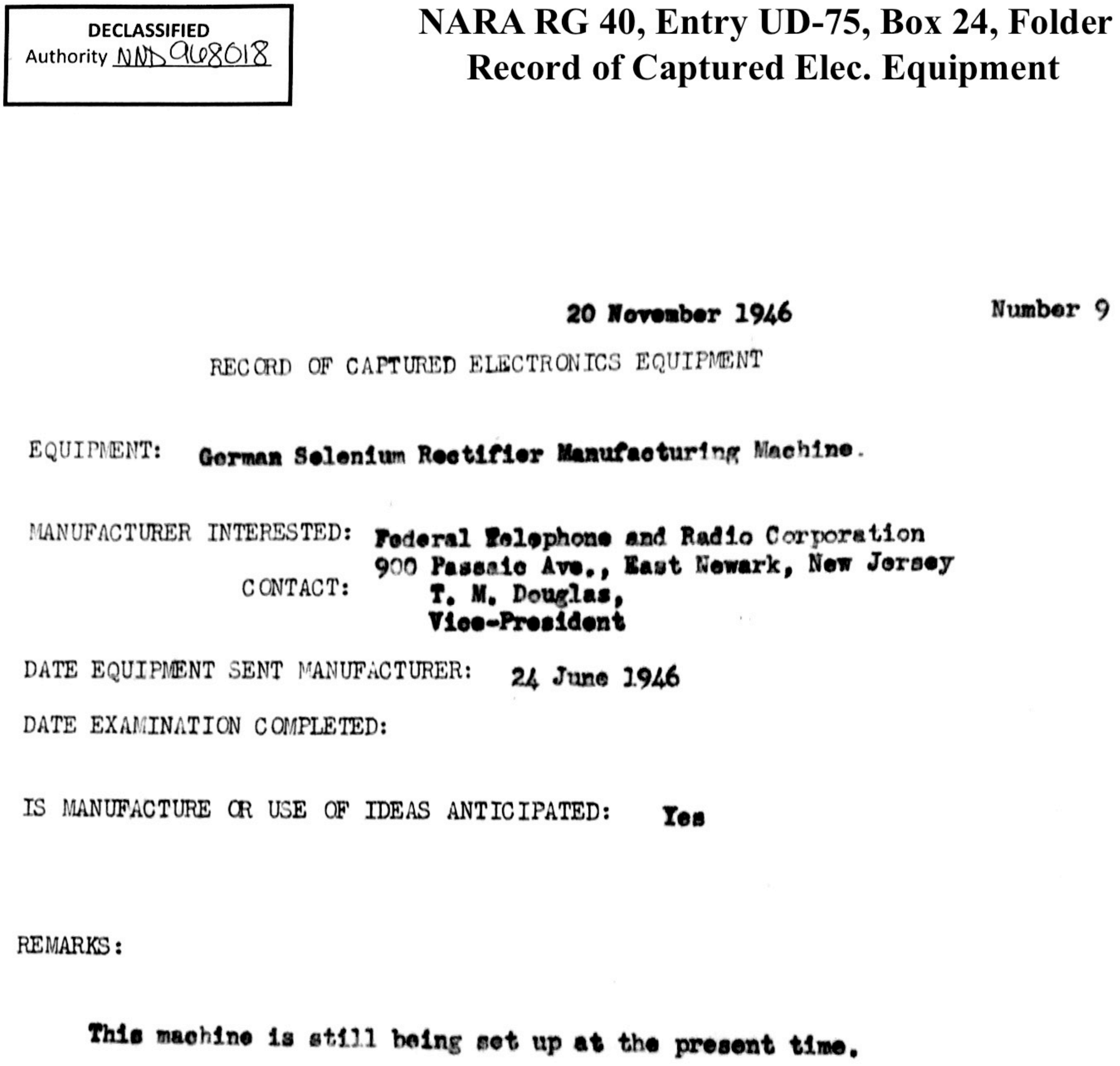
REMARKS:

Tubes shipped included the following types:

- RL
- LV
- RV
- LG
- LD
- LS
- EZ
- RS
- STV
- TS
- RD
- NF
- LB
- LD
- D1F
- UY
- FZ
- UX
- KX
- LMS

Testing and examination still in process this date.

Figure B.291: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment

20 November 1946 Number 9

RECORD OF CAPTURED ELECTRONICS EQUIPMENT

EQUIPMENT: German Selenium Rectifier Manufacturing Machine.

MANUFACTURER INTERESTED: Federal Telephone and Radio Corporation
900 Passaic Ave., East Newark, New Jersey
CONTACT: T. M. Douglas,
Vice-President

DATE EQUIPMENT SENT MANUFACTURER: 24 June 1946

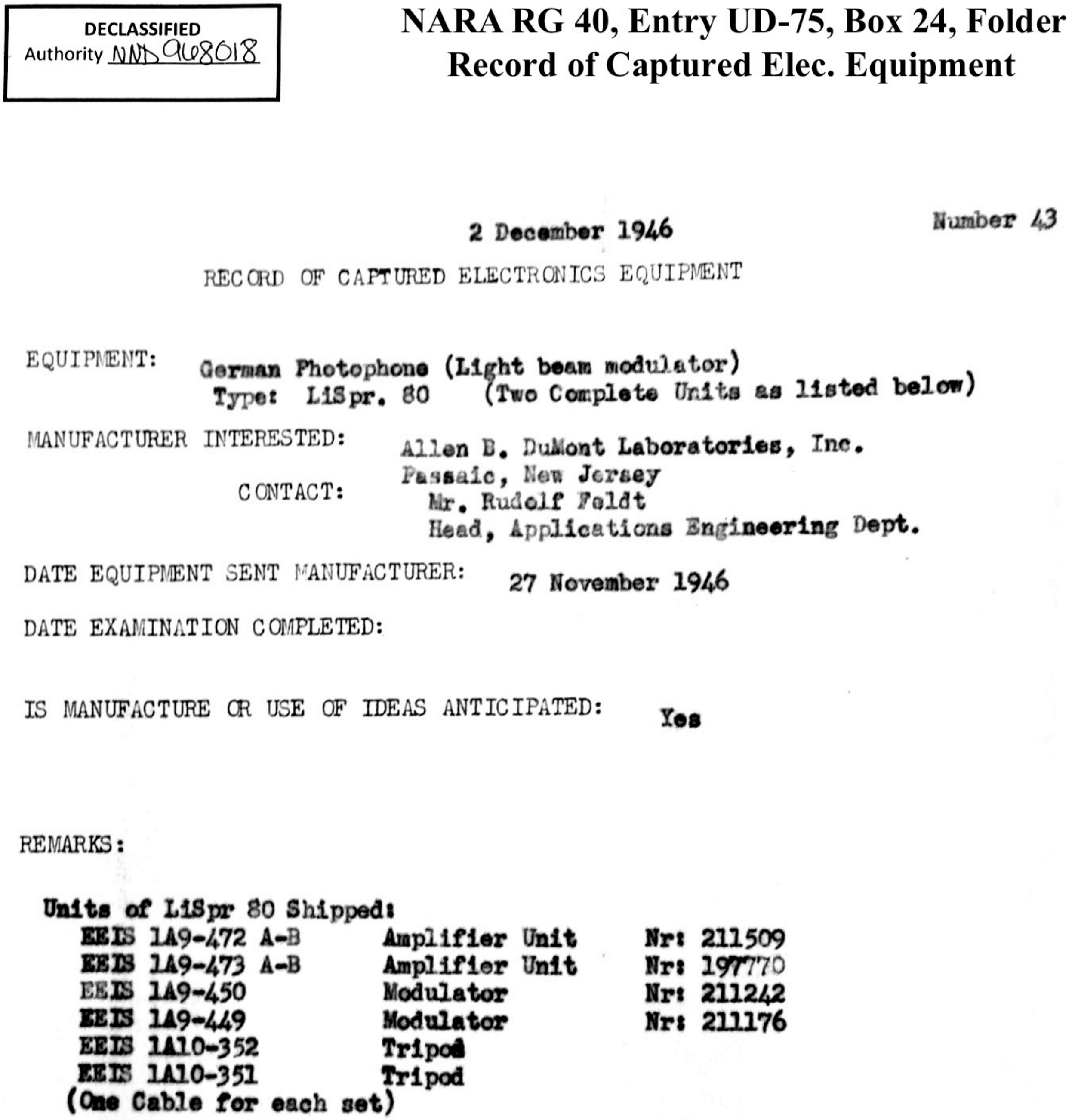
DATE EXAMINATION COMPLETED:

IS MANUFACTURE OR USE OF IDEAS ANTICIPATED: Yes

REMARKS:

This machine is still being set up at the present time.

Figure B.292: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment

2 December 1946 Number 43

RECORD OF CAPTURED ELECTRONICS EQUIPMENT

EQUIPMENT: German Photophone (Light beam modulator)
Type: LiSpr. 80 (Two Complete Units as listed below)

MANUFACTURER INTERESTED: Allen B. DuMont Laboratories, Inc.
Passaic, New Jersey
CONTACT: Mr. Rudolf Feldt
Head, Applications Engineering Dept.

DATE EQUIPMENT SENT MANUFACTURER: 27 November 1946

DATE EXAMINATION COMPLETED:

IS MANUFACTURE OR USE OF IDEAS ANTICIPATED: Yes

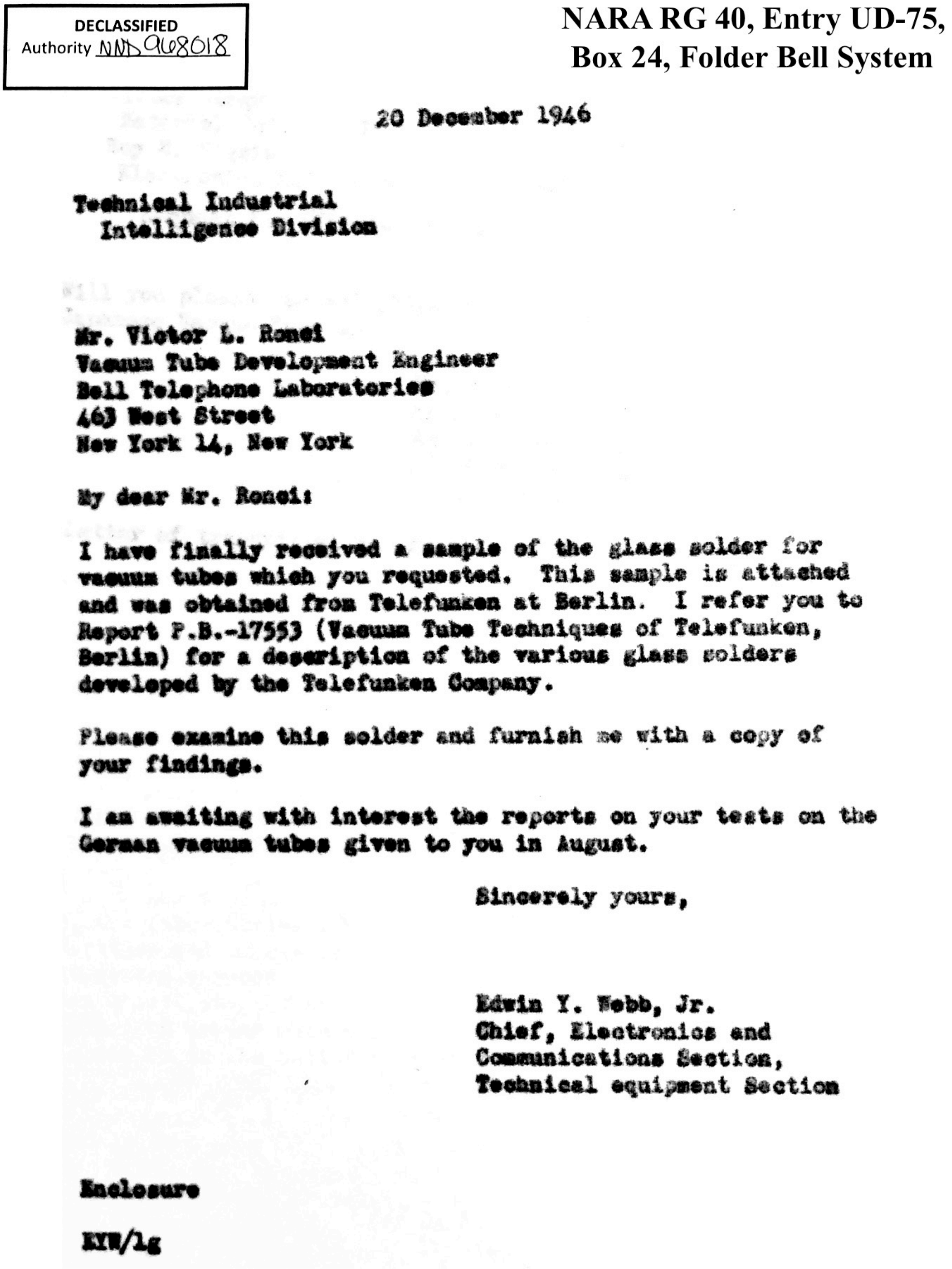
REMARKS:

Units of LiSpr 80 Shipped:

EEIS 1A9-472 A-B	Amplifier Unit	Nr: 211509
EEIS 1A9-473 A-B	Amplifier Unit	Nr: 197770
EEIS 1A9-450	Modulator	Nr: 211242
EEIS 1A9-449	Modulator	Nr: 211176
EEIS 1A10-352	Tripod	
EEIS 1A10-351	Tripod	

(One Cable for each set)

Figure B.293: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

20 December 1946

Technical Industrial
Intelligence Division

Mr. Victor L. Ronci
Vacuum Tube Development Engineer
Bell Telephone Laboratories
463 West Street
New York 14, New York

My dear Mr. Ronci:

I have finally received a sample of the glass solder for vacuum tubes which you requested. This sample is attached and was obtained from Telefunken at Berlin. I refer you to Report P.B.-17553 (Vacuum Tube Techniques of Telefunken, Berlin) for a description of the various glass solders developed by the Telefunken Company.

Please examine this solder and furnish me with a copy of your findings.

I am awaiting with interest the reports on your tests on the German vacuum tubes given to you in August.

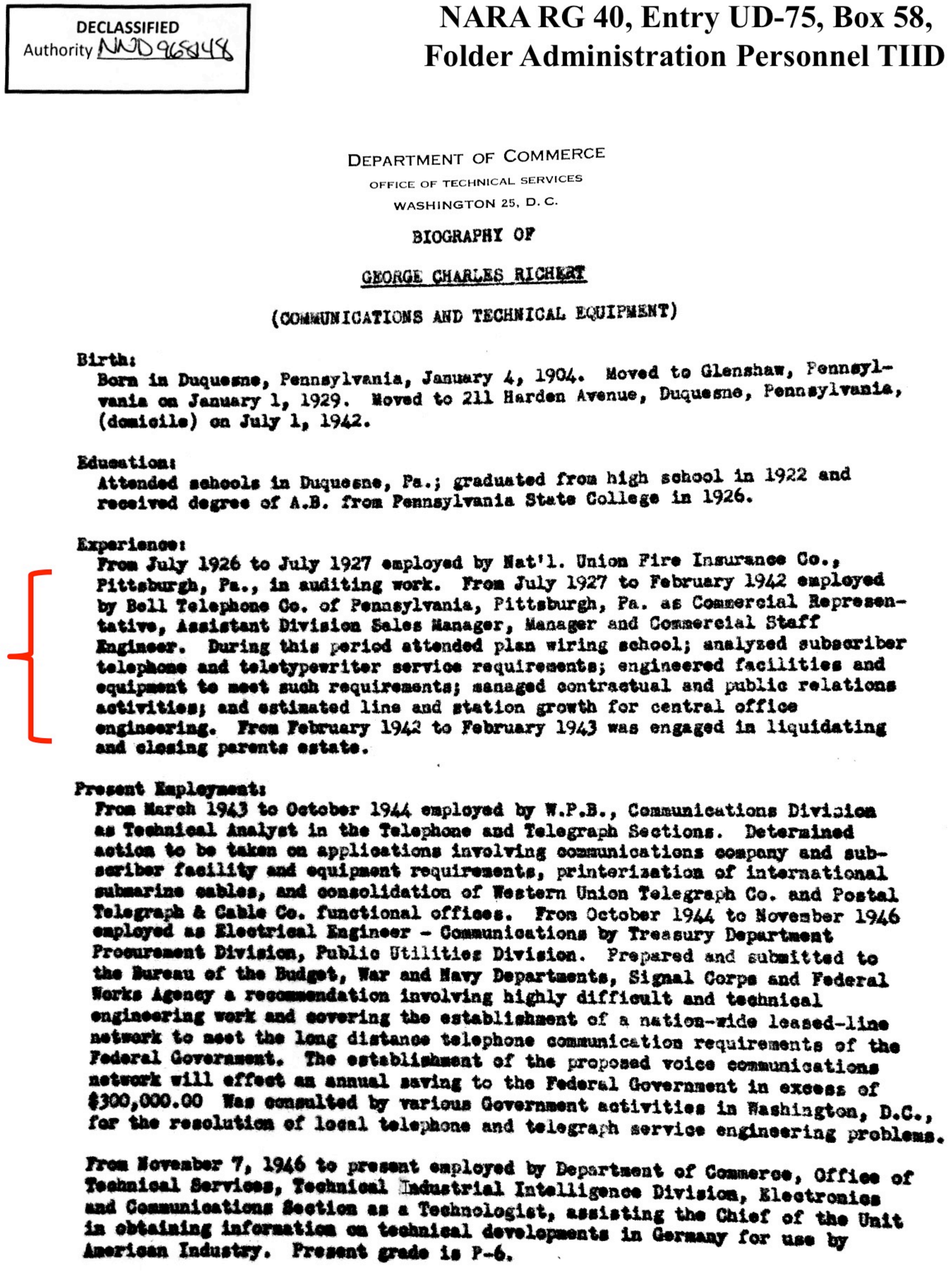
Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Electronics and
Communications Section,
Technical equipment Section

Enclosure

EYW/lg

Figure B.294: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID

DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES
WASHINGTON 25, D. C.

BIOGRAPHY OF

GEORGE CHARLES RICHERT

(COMMUNICATIONS AND TECHNICAL EQUIPMENT)

Birth:
Born in Duquesne, Pennsylvania, January 4, 1904. Moved to Glenshaw, Pennsylvania on January 1, 1929. Moved to 211 Harden Avenue, Duquesne, Pennsylvania, (domicile) on July 1, 1942.

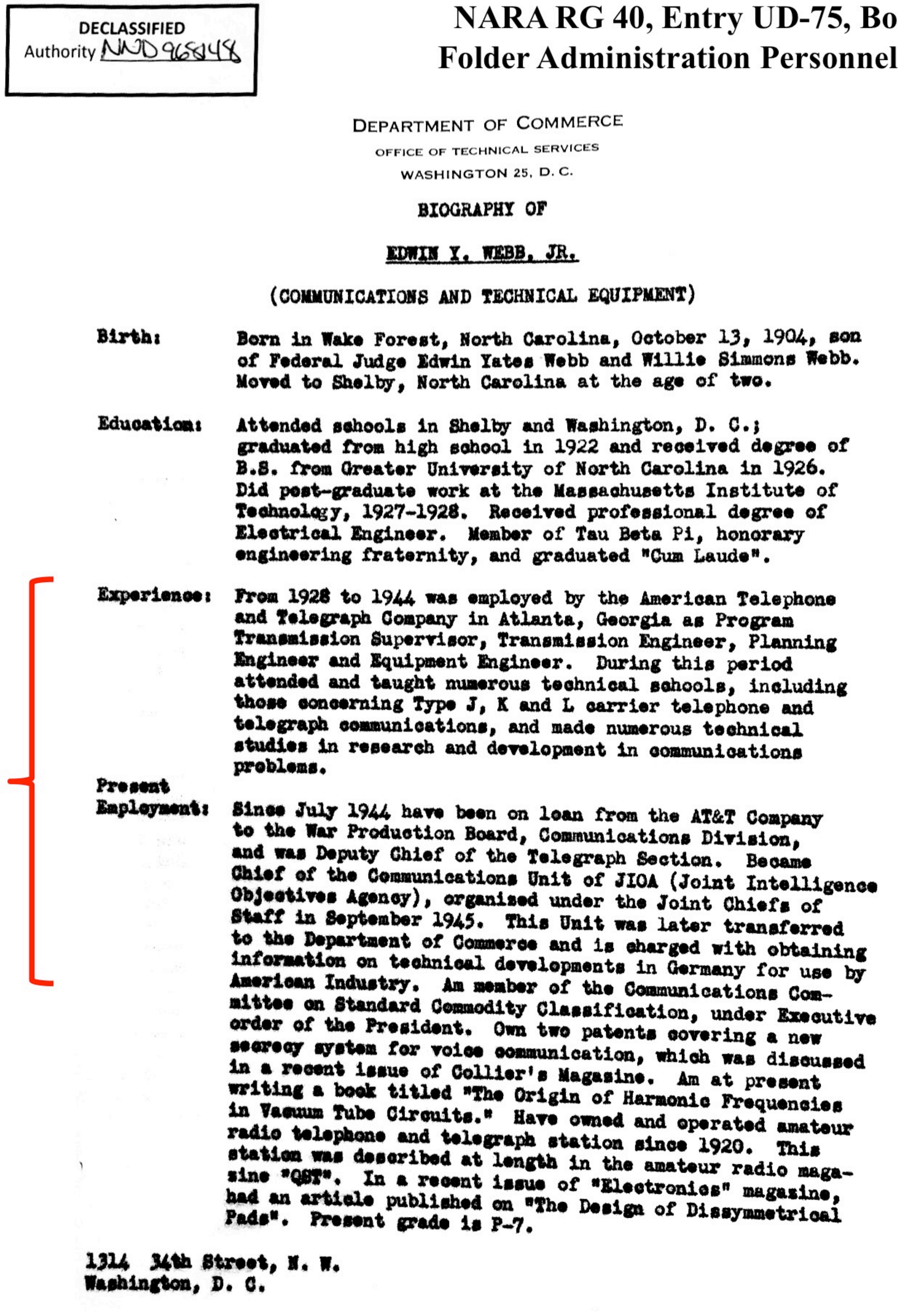
Education:
Attended schools in Duquesne, Pa.; graduated from high school in 1922 and received degree of A.B. from Pennsylvania State College in 1926.

Experience:
From July 1926 to July 1927 employed by Nat'l. Union Fire Insurance Co., Pittsburgh, Pa., in auditing work. From July 1927 to February 1942 employed by Bell Telephone Co. of Pennsylvania, Pittsburgh, Pa. as Commercial Representative, Assistant Division Sales Manager, Manager and Commercial Staff Engineer. During this period attended plan wiring school; analyzed subscriber telephone and teletypewriter service requirements; engineered facilities and equipment to meet such requirements; managed contractual and public relations activities; and estimated line and station growth for central office engineering. From February 1942 to February 1943 was engaged in liquidating and closing parents estate.

Present Employment:
From March 1943 to October 1944 employed by W.P.B., Communications Division as Technical Analyst in the Telephone and Telegraph Sections. Determined action to be taken on applications involving communications company and subscriber facility and equipment requirements, printerization of international submarine cables, and consolidation of Western Union Telegraph Co. and Postal Telegraph & Cable Co. functional offices. From October 1944 to November 1946 employed as Electrical Engineer - Communications by Treasury Department Procurement Division, Public Utilities Division. Prepared and submitted to the Bureau of the Budget, War and Navy Departments, Signal Corps and Federal Works Agency a recommendation involving highly difficult and technical engineering work and covering the establishment of a nation-wide leased-line network to meet the long distance telephone communication requirements of the Federal Government. The establishment of the proposed voice communications network will effect an annual saving to the Federal Government in excess of $300,000.00 Was consulted by various Government activities in Washington, D.C., for the resolution of local telephone and telegraph service engineering problems.

From November 7, 1946 to present employed by Department of Commerce, Office of Technical Services, Technical Industrial Intelligence Division, Electronics and Communications Section as a Technologist, assisting the Chief of the Unit in obtaining information on technical developments in Germany for use by American Industry. Present grade is P-6.

Figure B.295: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID

DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES
WASHINGTON 25, D. C.

BIOGRAPHY OF

EDWIN Y. WEBB, JR.

(COMMUNICATIONS AND TECHNICAL EQUIPMENT)

Birth: Born in Wake Forest, North Carolina, October 13, 1904, son of Federal Judge Edwin Yates Webb and Willie Simmons Webb. Moved to Shelby, North Carolina at the age of two.

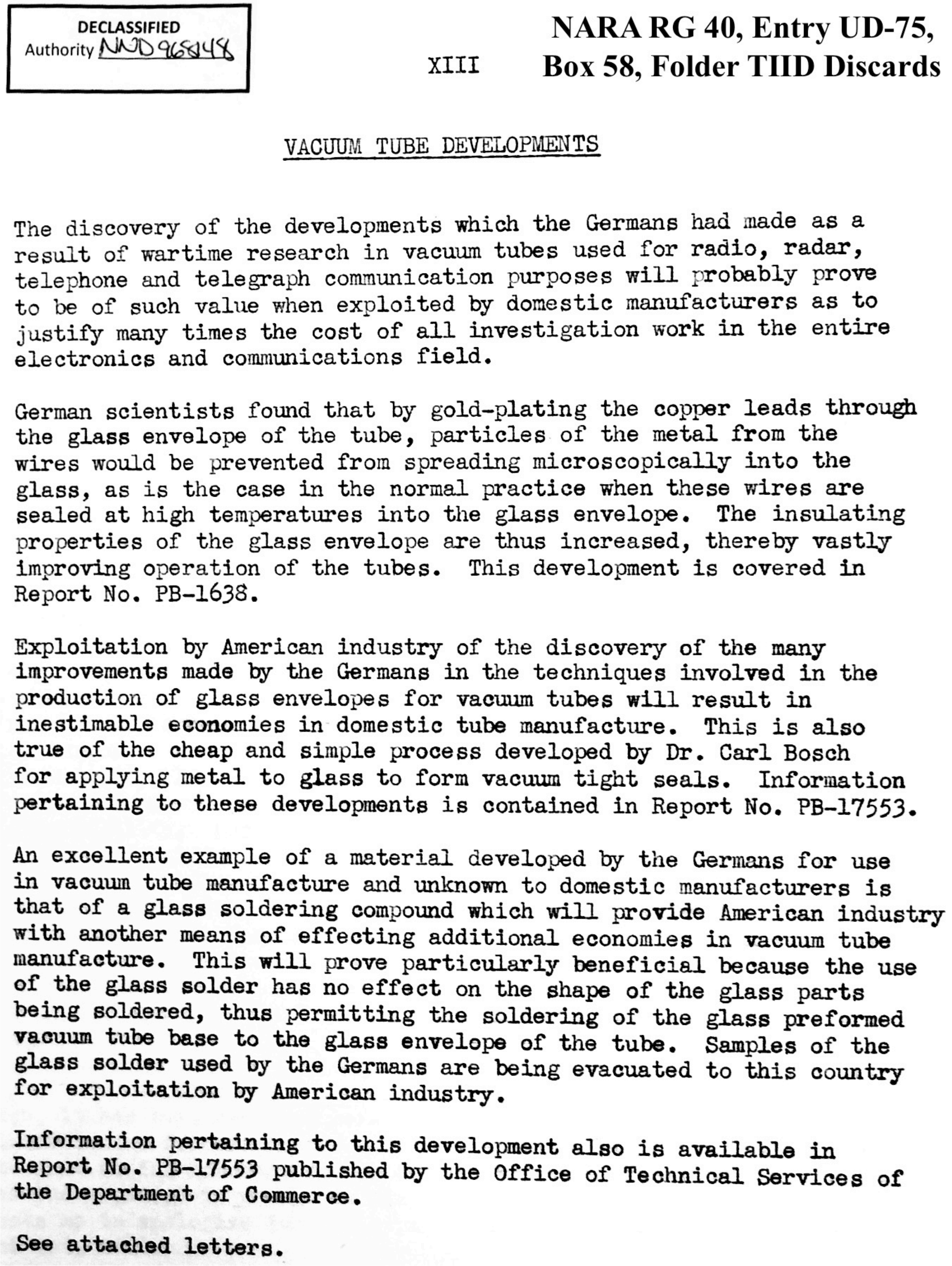
Education: Attended schools in Shelby and Washington, D. C.; graduated from high school in 1922 and received degree of B.S. from Greater University of North Carolina in 1926. Did post-graduate work at the Massachusetts Institute of Technology, 1927-1928. Received professional degree of Electrical Engineer. Member of Tau Beta Pi, honorary engineering fraternity, and graduated "Cum Laude".

Experience: From 1928 to 1944 was employed by the American Telephone and Telegraph Company in Atlanta, Georgia as Program Transmission Supervisor, Transmission Engineer, Planning Engineer and Equipment Engineer. During this period attended and taught numerous technical schools, including those concerning Type J, K and L carrier telephone and telegraph communications, and made numerous technical studies in research and development in communications problems.

Present Employment: Since July 1944 have been on loan from the AT&T Company to the War Production Board, Communications Division, and was Deputy Chief of the Telegraph Section. Became Chief of the Communications Unit of JIOA (Joint Intelligence Objectives Agency), organised under the Joint Chiefs of Staff in September 1945. This Unit was later transferred to the Department of Commerce and is charged with obtaining information on technical developments in Germany for use by American Industry. Am member of the Communications Committee on Standard Commodity Classification, under Executive order of the President. Own two patents covering a new secrecy system for voice communication, which was discussed in a recent issue of Collier's Magazine. Am at present writing a book titled "The Origin of Harmonic Frequencies in Vacuum Tube Circuits." Have owned and operated amateur radio telephone and telegraph station since 1920. This station was described at length in the amateur radio magazine "QST". In a recent issue of "Electronics" magazine, had an article published on "The Design of Dissymmetrical Pads". Present grade is P-7.

1314 34th Street, N. W.
Washington, D. C.

Figure B.296: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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XIII

NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards

VACUUM TUBE DEVELOPMENTS

The discovery of the developments which the Germans had made as a result of wartime research in vacuum tubes used for radio, radar, telephone and telegraph communication purposes will probably prove to be of such value when exploited by domestic manufacturers as to justify many times the cost of all investigation work in the entire electronics and communications field.

German scientists found that by gold-plating the copper leads through the glass envelope of the tube, particles of the metal from the wires would be prevented from spreading microscopically into the glass, as is the case in the normal practice when these wires are sealed at high temperatures into the glass envelope. The insulating properties of the glass envelope are thus increased, thereby vastly improving operation of the tubes. This development is covered in Report No. PB-1638.

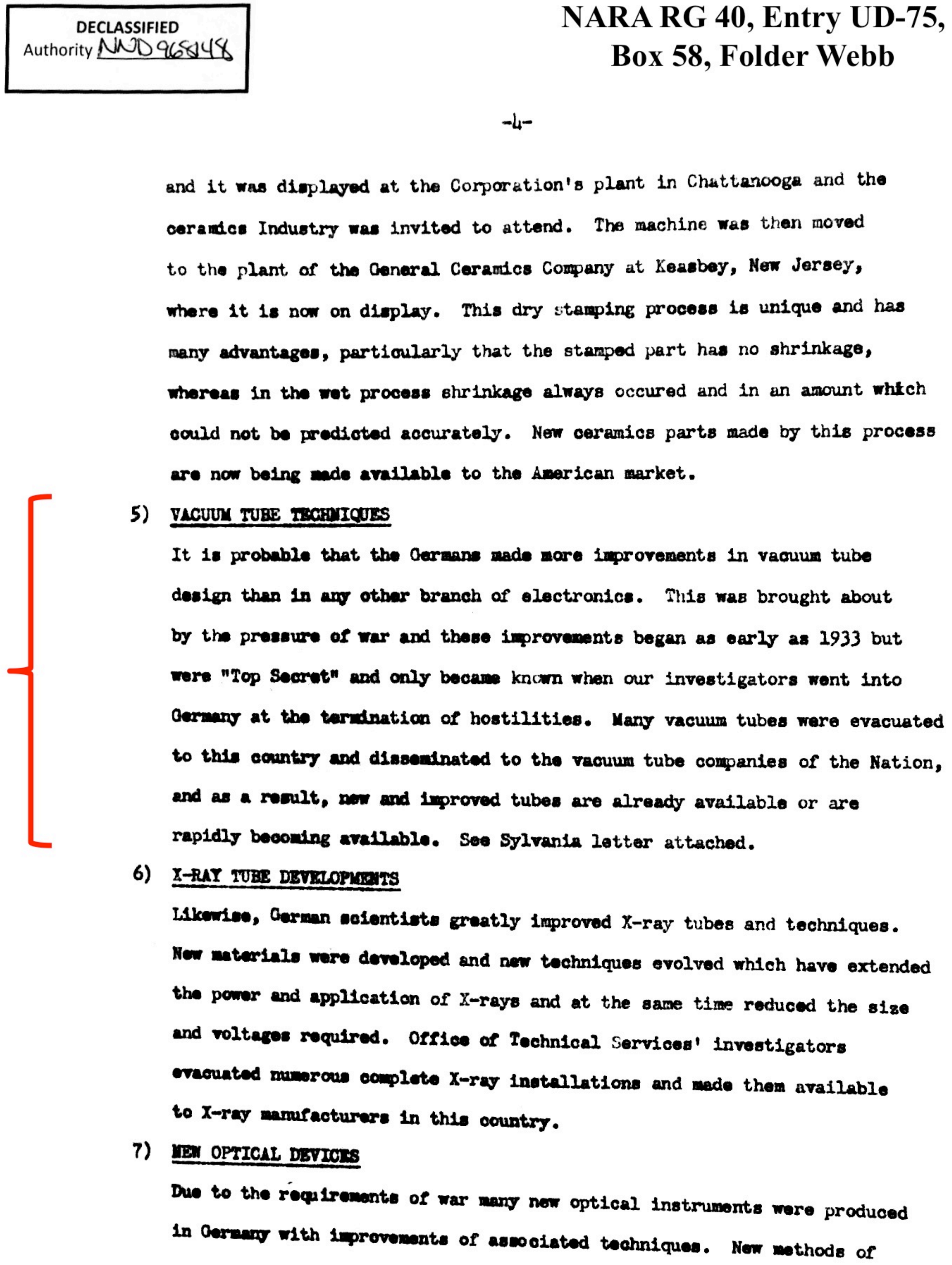
Exploitation by American industry of the discovery of the many improvements made by the Germans in the techniques involved in the production of glass envelopes for vacuum tubes will result in inestimable economies in domestic tube manufacture. This is also true of the cheap and simple process developed by Dr. Carl Bosch for applying metal to glass to form vacuum tight seals. Information pertaining to these developments is contained in Report No. PB-17553.

An excellent example of a material developed by the Germans for use in vacuum tube manufacture and unknown to domestic manufacturers is that of a glass soldering compound which will provide American industry with another means of effecting additional economies in vacuum tube manufacture. This will prove particularly beneficial because the use of the glass solder has no effect on the shape of the glass parts being soldered, thus permitting the soldering of the glass preformed vacuum tube base to the glass envelope of the tube. Samples of the glass solder used by the Germans are being evacuated to this country for exploitation by American industry.

Information pertaining to this development also is available in Report No. PB-17553 published by the Office of Technical Services of the Department of Commerce.

See attached letters.

Figure B.297: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder Webb

-4-

and it was displayed at the Corporation's plant in Chattanooga and the ceramics Industry was invited to attend. The machine was then moved to the plant of the General Ceramics Company at Keasbey, New Jersey, where it is now on display. This dry stamping process is unique and has many advantages, particularly that the stamped part has no shrinkage, whereas in the wet process shrinkage always occured and in an amount which could not be predicted accurately. New ceramics parts made by this process are now being made available to the American market.

5) VACUUM TUBE TECHNIQUES

It is probable that the Germans made more improvements in vacuum tube design than in any other branch of electronics. This was brought about by the pressure of war and these improvements began as early as 1933 but were "Top Secret" and only became known when our investigators went into Germany at the termination of hostilities. Many vacuum tubes were evacuated to this country and disseminated to the vacuum tube companies of the Nation, and as a result, new and improved tubes are already available or are rapidly becoming available. See Sylvania letter attached.

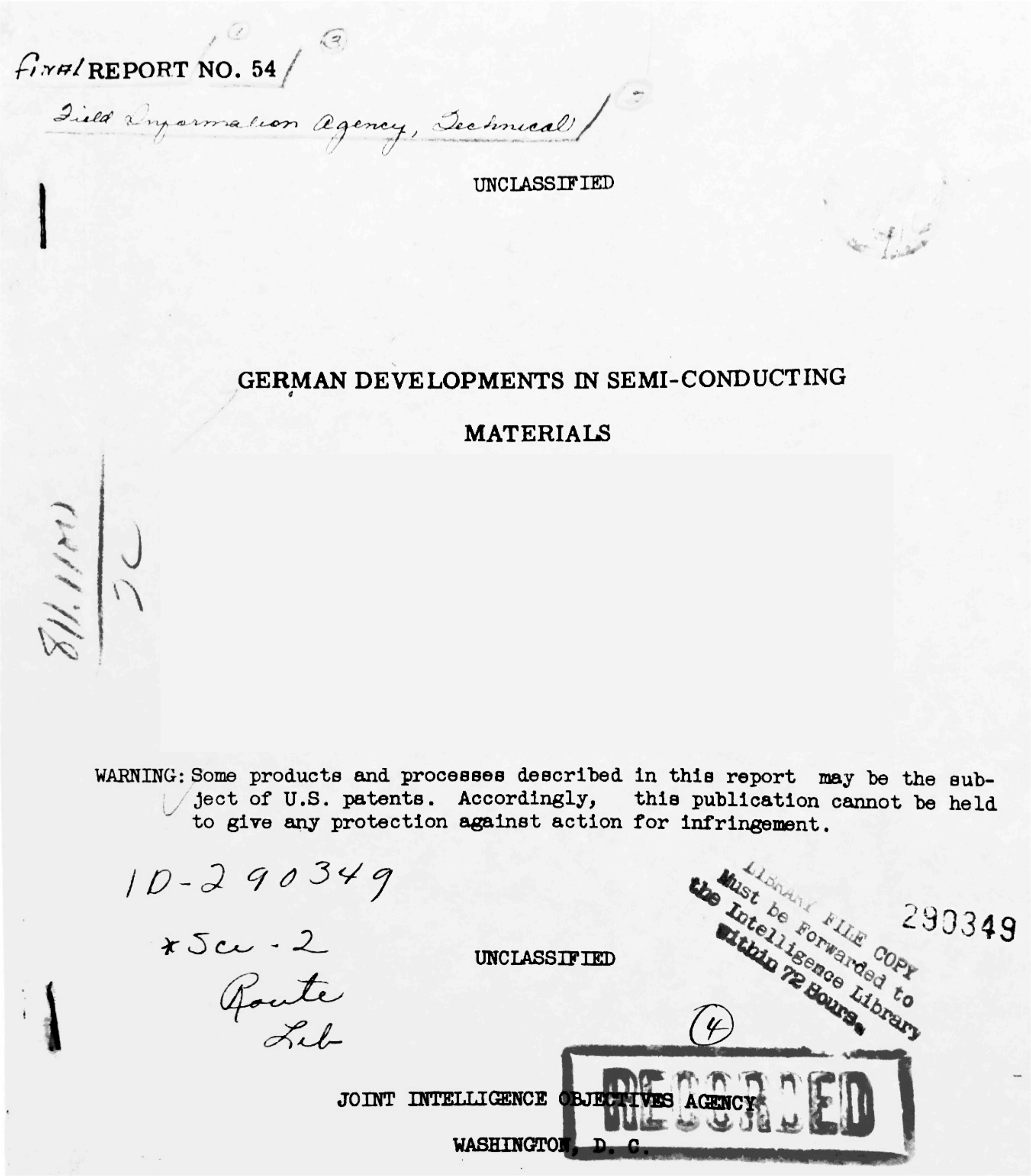
6) X-RAY TUBE DEVELOPMENTS

Likewise, German scientists greatly improved X-ray tubes and techniques. New materials were developed and new techniques evolved which have extended the power and application of X-rays and at the same time reduced the size and voltages required. Office of Technical Services' investigators evacuated numerous complete X-ray installations and made them available to X-ray manufacturers in this country.

7) NEW OPTICAL DEVICES

Due to the requirements of war many new optical instruments were produced in Germany with improvements of associated techniques. New methods of

Figure B.298: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder Webb]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



Final REPORT NO. 54

Field Information Agency, Technical

UNCLASSIFIED

GERMAN DEVELOPMENTS IN SEMI-CONDUCTING MATERIALS

WARNING: Some products and processes described in this report may be the subject of U.S. patents. Accordingly, this publication cannot be held to give any protection against action for infringement.

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290349

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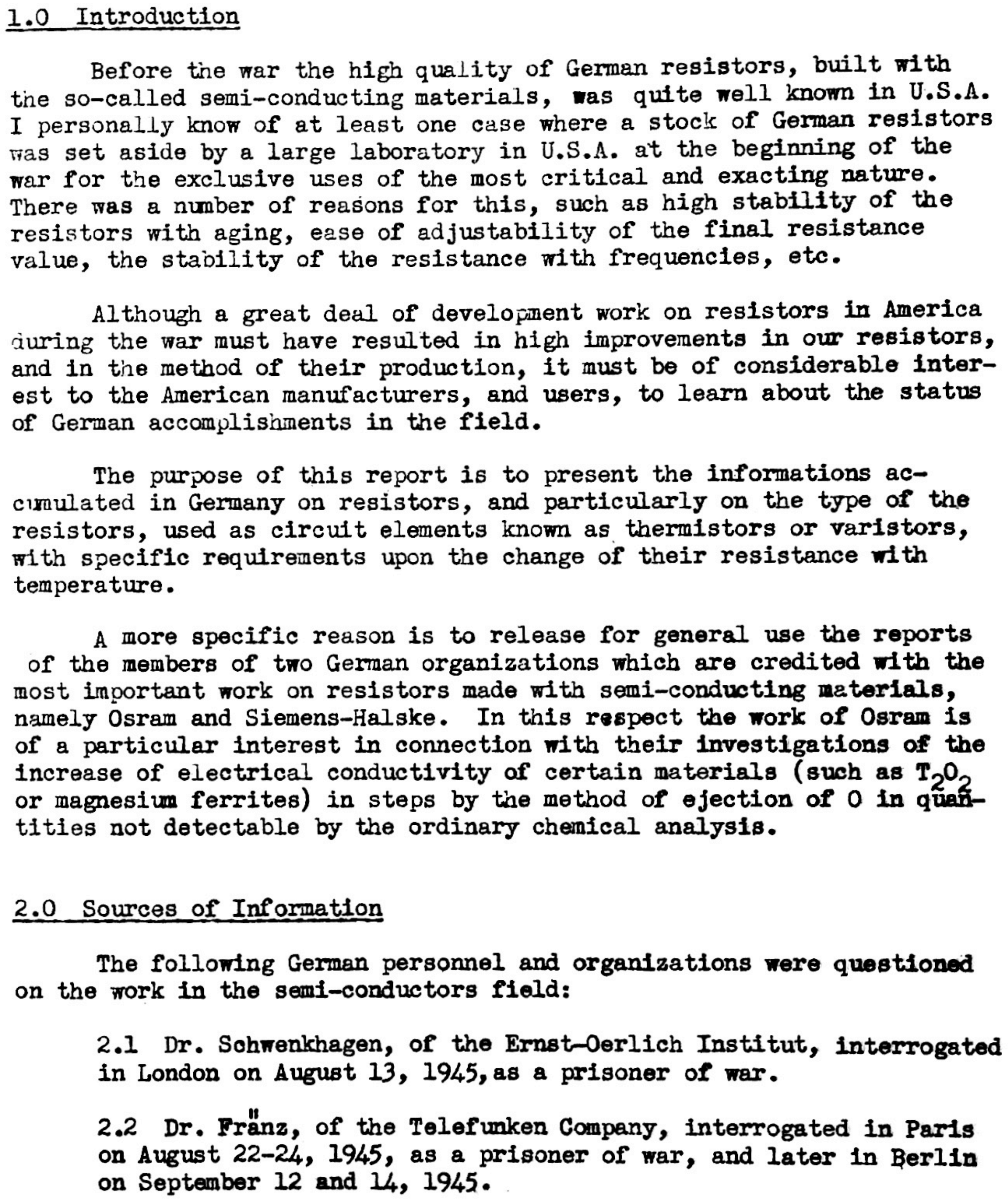
RECORDED

JOINT INTELLIGENCE OBJECTIVES AGENCY
WASHINGTON, D. C.

Figure B.299: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [FIAT 54]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



1.0 Introduction

Before the war the high quality of German resistors, built with the so-called semi-conducting materials, was quite well known in U.S.A. I personally know of at least one case where a stock of German resistors was set aside by a large laboratory in U.S.A. at the beginning of the war for the exclusive uses of the most critical and exacting nature. There was a number of reasons for this, such as high stability of the resistors with aging, ease of adjustability of the final resistance value, the stability of the resistance with frequencies, etc.

Although a great deal of development work on resistors in America during the war must have resulted in high improvements in our resistors, and in the method of their production, it must be of considerable interest to the American manufacturers, and users, to learn about the status of German accomplishments in the field.

The purpose of this report is to present the informations accumulated in Germany on resistors, and particularly on the type of the resistors, used as circuit elements known as thermistors or varistors, with specific requirements upon the change of their resistance with temperature.

A more specific reason is to release for general use the reports of the members of two German organizations which are credited with the most important work on resistors made with semi-conducting materials, namely Osram and Siemens-Halske. In this respect the work of Osram is of a particular interest in connection with their investigations of the increase of electrical conductivity of certain materials (such as T_2O_2 or magnesium ferrites) in steps by the method of ejection of O in quantities not detectable by the ordinary chemical analysis.

2.0 Sources of Information

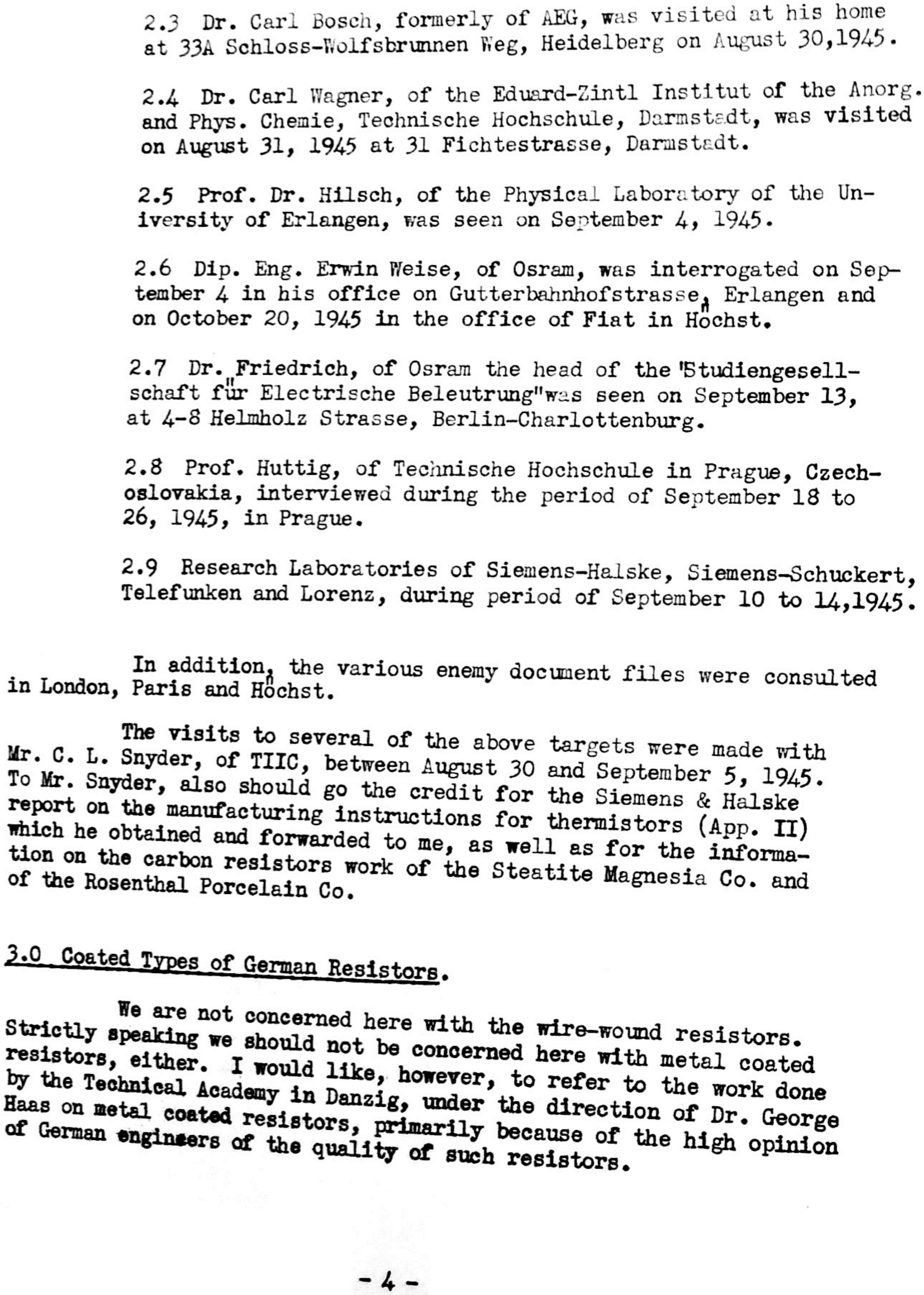
The following German personnel and organizations were questioned on the work in the semi-conductors field:

2.1 Dr. Schwenkhagen, of the Ernst-Oerlich Institut, interrogated in London on August 13, 1945, as a prisoner of war.

2.2 Dr. Fränz, of the Telefunken Company, interrogated in Paris on August 22-24, 1945, as a prisoner of war, and later in Berlin on September 12 and 14, 1945.

- 3 -

Figure B.300: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [FIAT 54]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



2.3 Dr. Carl Bosch, formerly of AEG, was visited at his home at 33A Schloss-Wolfsbrunnen Weg, Heidelberg on August 30,1945.

2.4 Dr. Carl Wagner, of the Eduard-Zintl Institut of the Anorg. and Phys. Chemie, Technische Hochschule, Darmstadt, was visited on August 31, 1945 at 31 Fichtestrasse, Darmstadt.

2.5 Prof. Dr. Hilsch, of the Physical Laboratory of the University of Erlangen, was seen on September 4, 1945.

2.6 Dip. Eng. Erwin Weise, of Osram, was interrogated on September 4 in his office on Gutterbahnhofstrasse, Erlangen and on October 20, 1945 in the office of Fiat in Höchst.

2.7 Dr. Friedrich, of Osram the head of the "Studiengesellschaft für Electrische Beleutrung" was seen on September 13, at 4-8 Helmholz Strasse, Berlin-Charlottenburg.

2.8 Prof. Huttig, of Technische Hochschule in Prague, Czechoslovakia, interviewed during the period of September 18 to 26, 1945, in Prague.

2.9 Research Laboratories of Siemens-Halske, Siemens-Schuckert, Telefunken and Lorenz, during period of September 10 to 14,1945.

In addition, the various enemy document files were consulted in London, Paris and Höchst.

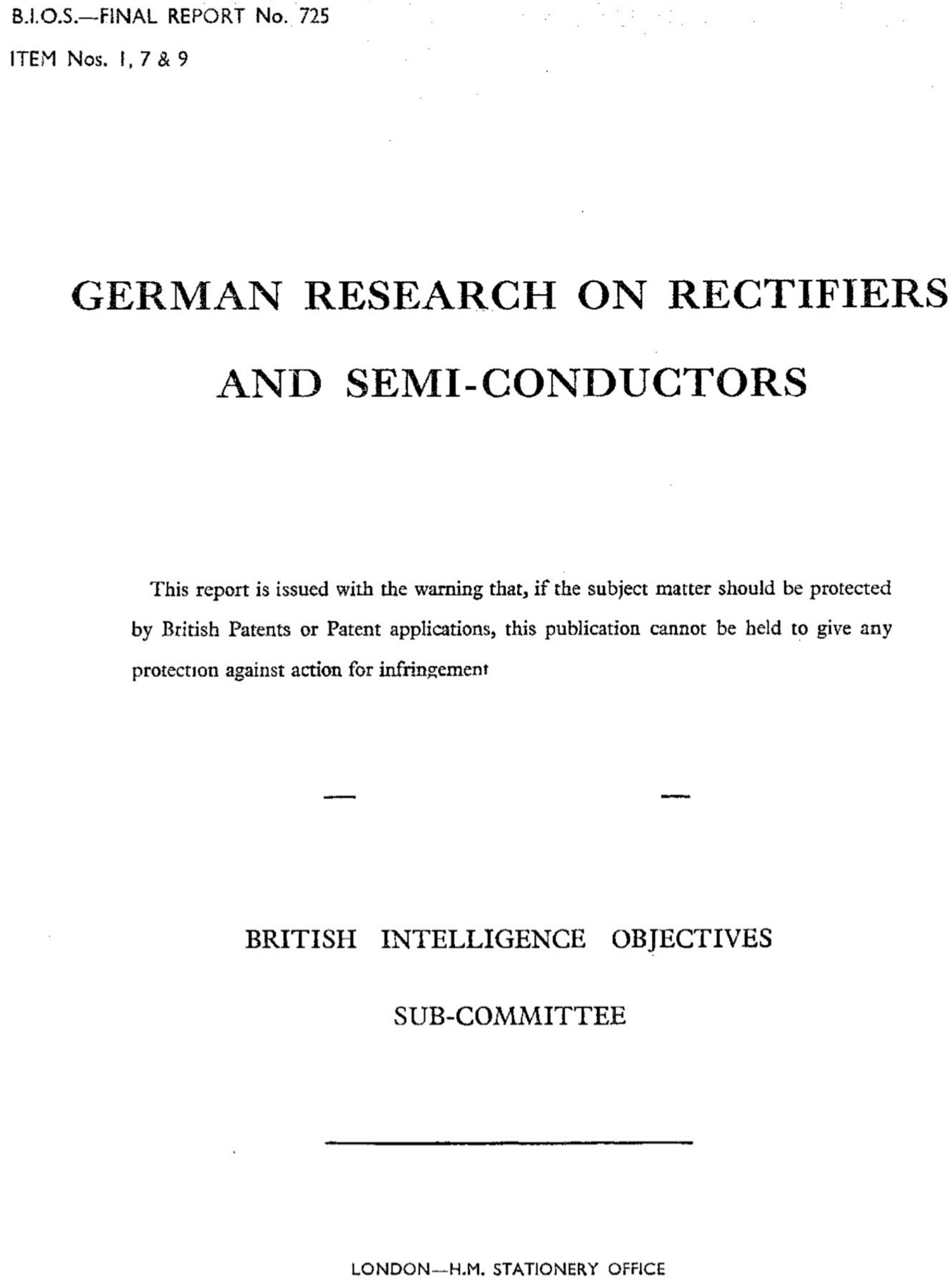
The visits to several of the above targets were made with Mr. C. L. Snyder, of TIIC, between August 30 and September 5, 1945. To Mr. Snyder, also should go the credit for the Siemens & Halske report on the manufacturing instructions for thermistors (App. II) which he obtained and forwarded to me, as well as for the information on the carbon resistors work of the Steatite Magnesia Co. and of the Rosenthal Porcelain Co.

3.0 Coated Types of German Resistors.

We are not concerned here with the wire-wound resistors. Strictly speaking we should not be concerned here with metal coated resistors, either. I would like, however, to refer to the work done by the Technical Academy in Danzig, under the direction of Dr. George Haas on metal coated resistors, primarily because of the high opinion of German engineers of the quality of such resistors.

- 4 -

Figure B.301: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [FIAT 54]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



B.I.O.S.—FINAL REPORT No. 725

ITEM Nos. 1, 7 & 9

GERMAN RESEARCH ON RECTIFIERS AND SEMI-CONDUCTORS

This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

Figure B.302: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

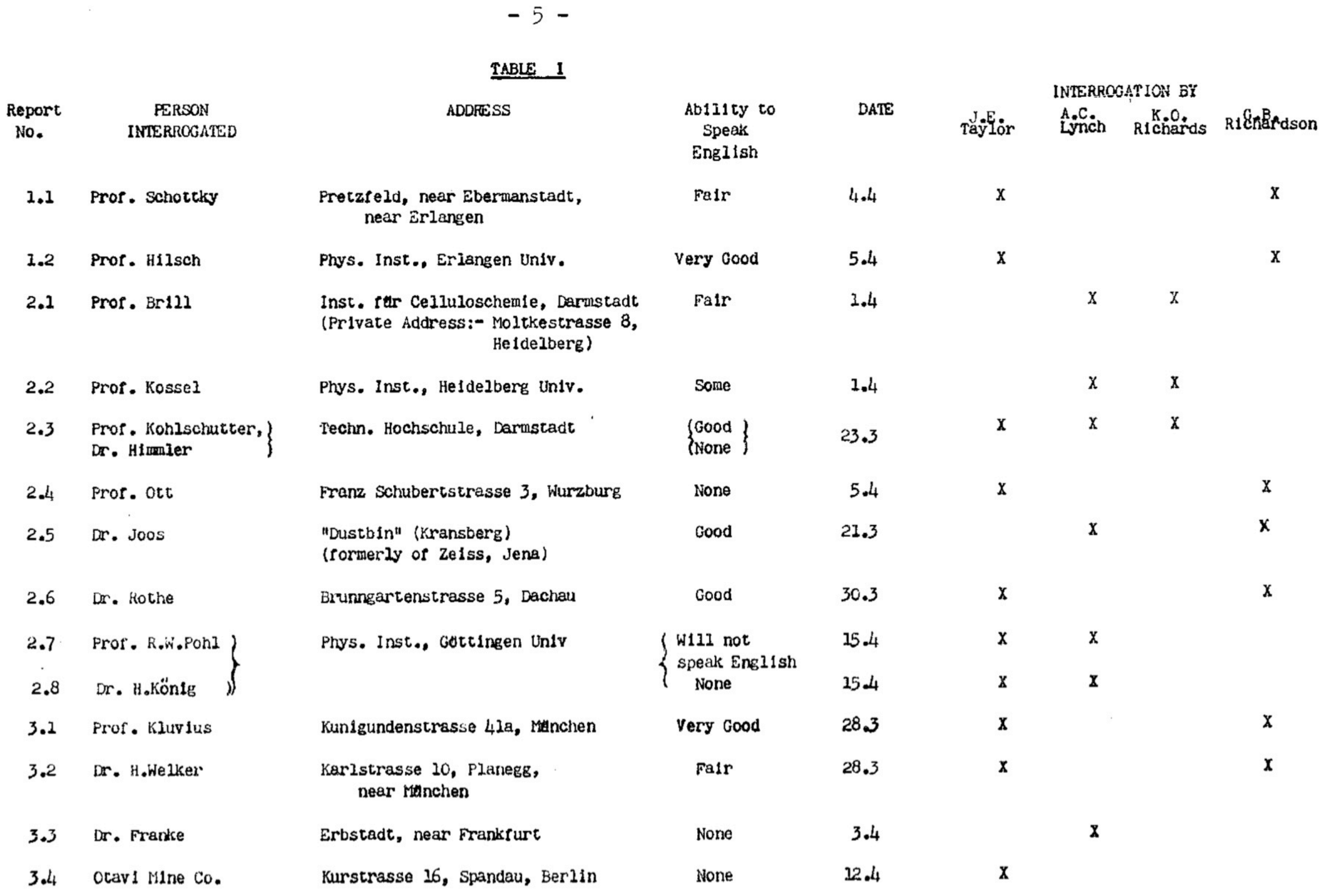

TABLE I

Report No.	PERSON INTERROGATED	ADDRESS	Ability to Speak English	DATE	INTERROGATION BY J.E. Taylor	A.C. Lynch	K.O. Richards	G.B. Richardson
1.1	Prof. Schottky	Pretzfeld, near Ebermanstadt, near Erlangen	Fair	4.4	X			X
1.2	Prof. Hilsch	Phys. Inst., Erlangen Univ.	Very Good	5.4	X			X
2.1	Prof. Brill	Inst. für Celluloschemie, Darmstadt (Private Address:- Moltkestrasse 8, Heidelberg)	Fair	1.4		X	X	
2.2	Prof. Kossel	Phys. Inst., Heidelberg Univ.	Some	1.4		X	X	
2.3	Prof. Kohlschutter, Dr. Himmler	Techn. Hochschule, Darmstadt	Good None	23.3	X	X	X	
2.4	Prof. Ott	Franz Schubertstrasse 3, Wurzburg	None	5.4	X			X
2.5	Dr. Joos	"Dustbin" (Kransberg) (formerly of Zeiss, Jena)	Good	21.3		X		X
2.6	Dr. Rothe	Brunngartenstrasse 5, Dachau	Good	30.3	X			X
2.7	Prof. R.W.Pohl	Phys. Inst., Göttingen Univ	Will not speak English	15.4	X	X		
2.8	Dr. H.König		None	15.4	X	X		
3.1	Prof. Kluvius	Kunigundenstrasse 41a, München	Very Good	28.3	X			X
3.2	Dr. H.Welker	Karlstrasse 10, Planegg, near München	Fair	28.3	X			X
3.3	Dr. Franke	Erbstadt, near Frankfurt	None	3.4		X		
3.4	Otavi Mine Co.	Kurstrasse 16, Spandau, Berlin	None	12.4	X			

Figure B.303: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

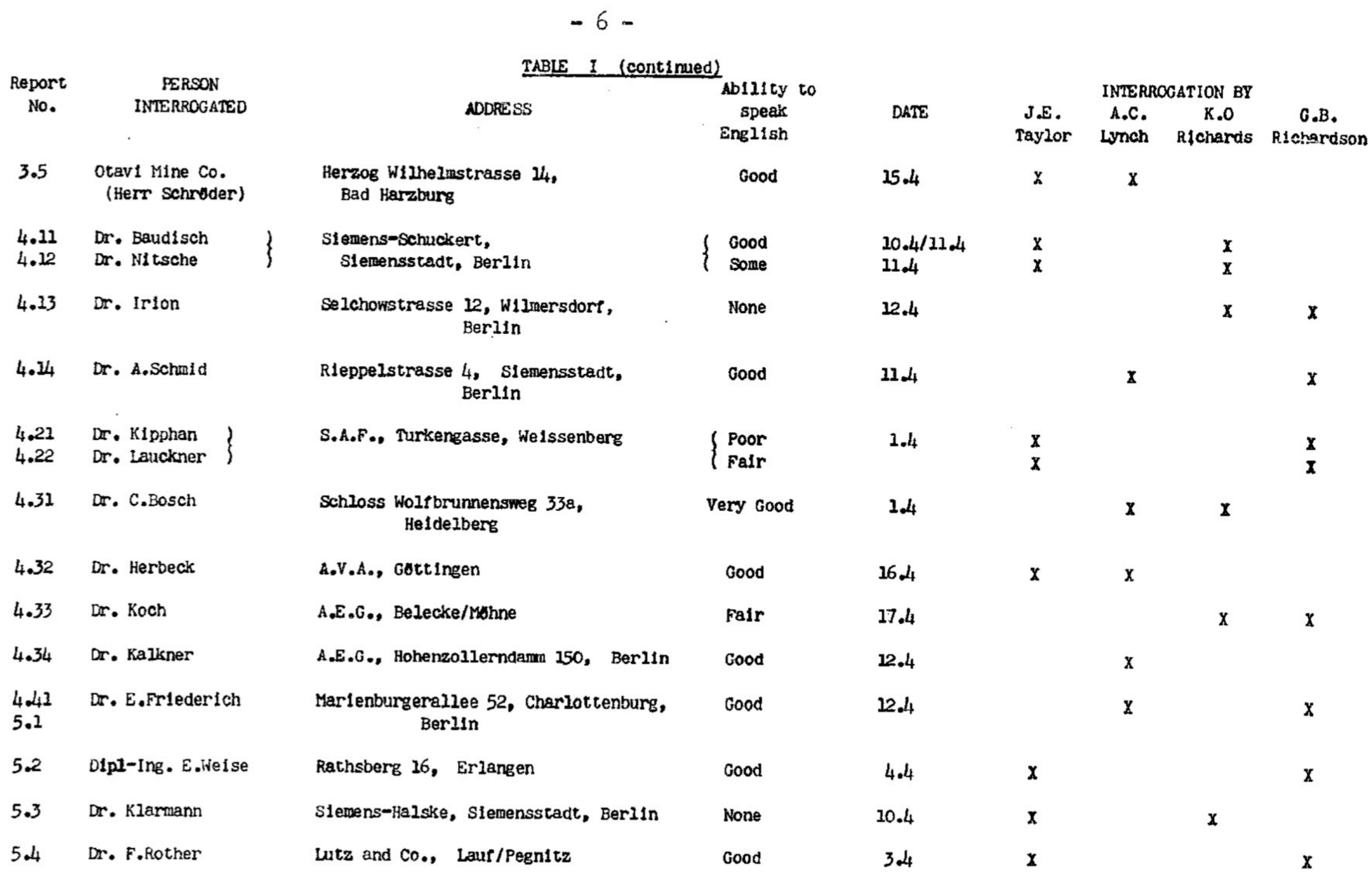

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TABLE I (continued)

Report No.	PERSON INTERROGATED	ADDRESS	Ability to speak English	DATE	INTERROGATION BY			
					J.E. Taylor	A.C. Lynch	K.O Richards	G.B. Richardson
3.5	Otavi Mine Co. (Herr Schröder)	Herzog Wilhelmstrasse 14, Bad Harzburg	Good	15.4	X	X		
4.11	Dr. Baudisch	Siemens-Schuckert, Siemensstadt, Berlin	Good	10.4/11.4	X		X	
4.12	Dr. Nitsche		Some	11.4	X		X	
4.13	Dr. Irion	Selchowstrasse 12, Wilmersdorf, Berlin	None	12.4			X	X
4.14	Dr. A.Schmid	Rieppelstrasse 4, Siemensstadt, Berlin	Good	11.4		X		X
4.21	Dr. Kipphan	S.A.F., Turkengasse, Weissenberg	Poor	1.4	X			X
4.22	Dr. Lauckner		Fair		X			X
4.31	Dr. C.Bosch	Schloss Wolfbrunnensweg 33a, Heidelberg	Very Good	1.4		X	X	
4.32	Dr. Herbeck	A.V.A., Göttingen	Good	16.4	X	X		
4.33	Dr. Koch	A.E.G., Belecke/Möhne	Fair	17.4			X	X
4.34	Dr. Kalkner	A.E.G., Hohenzollerndamm 150, Berlin	Good	12.4		X		
4.41 5.1	Dr. E.Friederich	Marienburgerallee 52, Charlottenburg, Berlin	Good	12.4		X		X
5.2	Dipl-Ing. E.Weise	Rathsberg 16, Erlangen	Good	4.4	X			X
5.3	Dr. Klarmann	Siemens-Halske, Siemensstadt, Berlin	None	10.4	X		X	
5.4	Dr. F.Rother	Lutz and Co., Lauf/Pegnitz	Good	3.4	X			X

Figure B.304: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

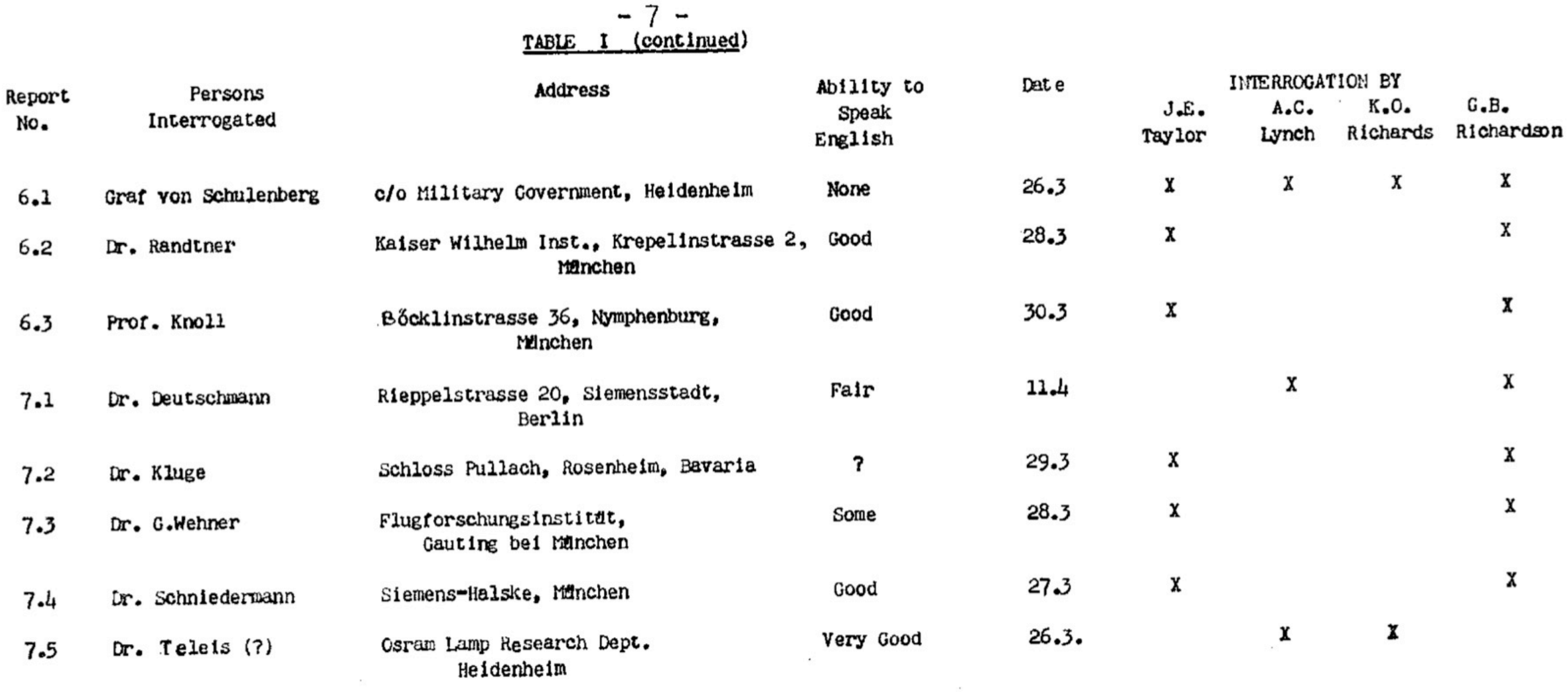

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TABLE I (continued)

Report No.	Persons Interrogated	Address	Ability to Speak English	Date	INTERROGATION BY J.E. Taylor	A.C. Lynch	K.O. Richards	G.B. Richardson
6.1	Graf von Schulenberg	c/o Military Government, Heidenheim	None	26.3	X	X	X	X
6.2	Dr. Randtner	Kaiser Wilhelm Inst., Krepelinstrasse 2, München	Good	28.3	X			X
6.3	Prof. Knoll	Böcklinstrasse 36, Nymphenburg, München	Good	30.3	X			X
7.1	Dr. Deutschmann	Rieppelstrasse 20, Siemensstadt, Berlin	Fair	11.4		X		X
7.2	Dr. Kluge	Schloss Pullach, Rosenheim, Bavaria	?	29.3	X			X
7.3	Dr. G.Wehner	Flugforschungsinstitut, Gauting bei München	Some	28.3	X			X
7.4	Dr. Schniedermann	Siemens-Halske, München	Good	27.3	X			X
7.5	Dr. Teleis (?)	Osram Lamp Research Dept. Heidenheim	Very Good	26.3.		X	X	

Figure B.305: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

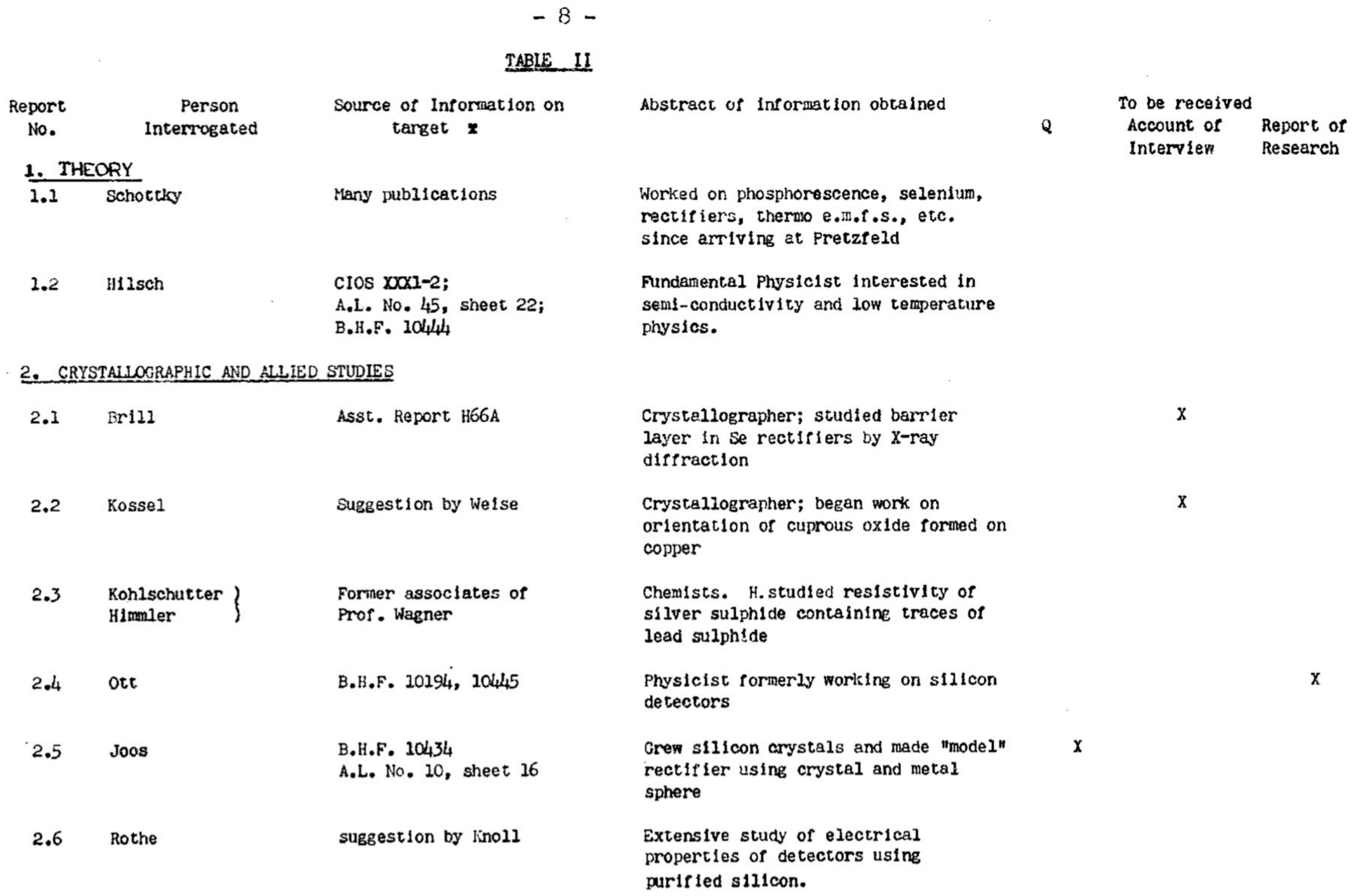

TABLE II

Report No.	Person Interrogated	Source of Information on target *	Abstract of information obtained	Q	To be received Account of Interview	Report of Research
1. THEORY						
1.1	Schottky	Many publications	Worked on phosphorescence, selenium, rectifiers, thermo e.m.f.s., etc. since arriving at Pretzfeld			
1.2	Hilsch	CIOS XXXI-2; A.L. No. 45, sheet 22; B.H.F. 10444	Fundamental Physicist interested in semi-conductivity and low temperature physics.			
2. CRYSTALLOGRAPHIC AND ALLIED STUDIES						
2.1	Brill	Asst. Report H66A	Crystallographer; studied barrier layer in Se rectifiers by X-ray diffraction		X	
2.2	Kossel	Suggestion by Weise	Crystallographer; began work on orientation of cuprous oxide formed on copper		X	
2.3	Kohlschutter } Himmler }	Former associates of Prof. Wagner	Chemists. H. studied resistivity of silver sulphide containing traces of lead sulphide			
2.4	Ott	B.H.F. 10194, 10445	Physicist formerly working on silicon detectors			X
2.5	Joos	B.H.F. 10434 A.L. No. 10, sheet 16	Grew silicon crystals and made "model" rectifier using crystal and metal sphere	X		
2.6	Rothe	suggestion by Knoll	Extensive study of electrical properties of detectors using purified silicon.			

Figure B.306: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

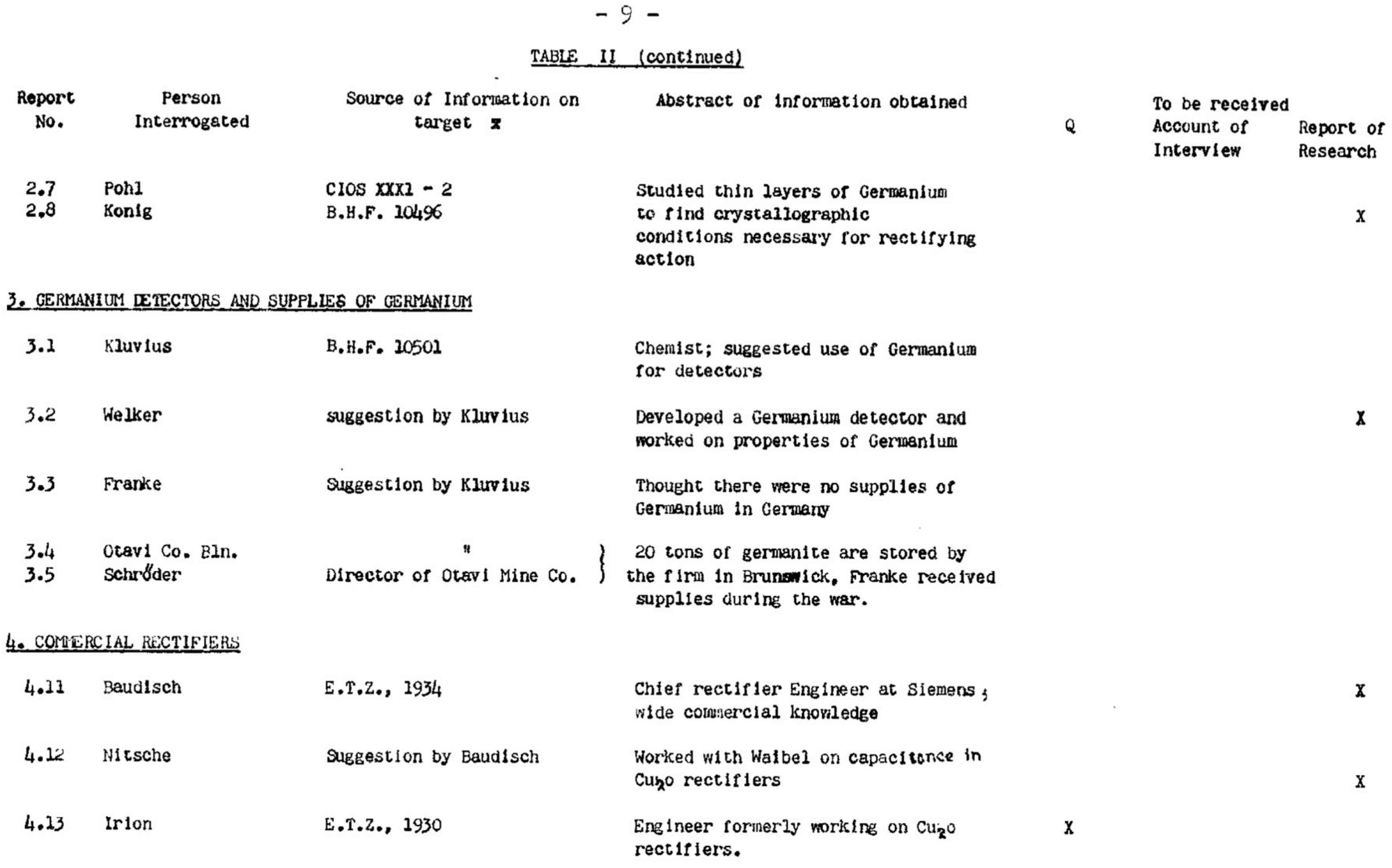

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TABLE II (continued)

Report No.	Person Interrogated	Source of Information on target x	Abstract of information obtained	Q	To be received Account of Interview	Report of Research
2.7 2.8	Pohl Konig	CIOS XXXI - 2 B.H.F. 10496	Studied thin layers of Germanium to find crystallographic conditions necessary for rectifying action			X
3. GERMANIUM DETECTORS AND SUPPLIES OF GERMANIUM						
3.1	Kluvius	B.H.F. 10501	Chemist; suggested use of Germanium for detectors			
3.2	Welker	suggestion by Kluvius	Developed a Germanium detector and worked on properties of Germanium			X
3.3	Franke	Suggestion by Kluvius	Thought there were no supplies of Germanium in Germany			
3.4 3.5	Otavi Co. Bln. Schröder	" Director of Otavi Mine Co.	20 tons of germanite are stored by the firm in Brunswick, Franke received supplies during the war.			
4. COMMERCIAL RECTIFIERS						
4.11	Baudisch	E.T.Z., 1934	Chief rectifier Engineer at Siemens; wide commercial knowledge			X
4.12	Nitsche	Suggestion by Baudisch	Worked with Waibel on capacitance in Cu_2O rectifiers			X
4.13	Irion	E.T.Z., 1930	Engineer formerly working on Cu_2O rectifiers.	X		

Figure B.307: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

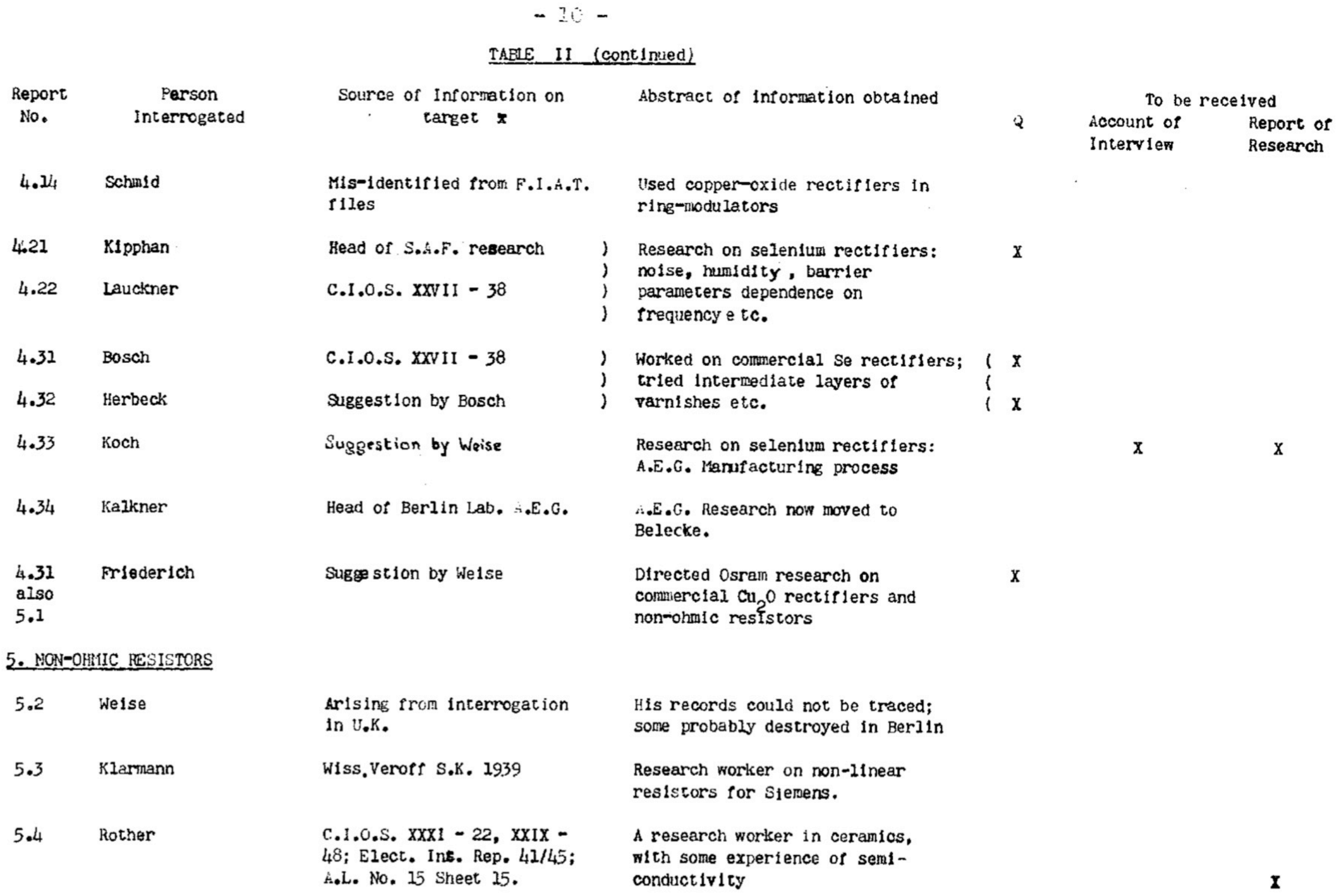

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TABLE II (continued)

Report No.	Person Interrogated	Source of Information on target *		Abstract of information obtained		Q	To be received Account of Interview	Report of Research
4.14	Schmid	Mis-identified from F.I.A.T. files		Used copper-oxide rectifiers in ring-modulators				
4.21	Kipphan	Head of S.A.F. research	)	Research on selenium rectifiers: noise, humidity , barrier parameters dependence on frequency e tc.		X		
4.22	Lauckner	C.I.O.S. XXVII - 38	)					
4.31	Bosch	C.I.O.S. XXVII - 38	)	Worked on commercial Se rectifiers; tried intermediate layers of varnishes etc.	(	X		
4.32	Herbeck	Suggestion by Bosch	)		(	X		
4.33	Koch	Suggestion by Weise		Research on selenium rectifiers: A.E.G. Manufacturing process			X	X
4.34	Kalkner	Head of Berlin Lab. A.E.G.		A.E.G. Research now moved to Belecke.				
4.31 also 5.1	Friederich	Suggestion by Weise		Directed Osram research on commercial Cu_2O rectifiers and non-ohmic resistors		X		
5. NON-OHMIC RESISTORS								
5.2	Weise	Arising from interrogation in U.K.		His records could not be traced; some probably destroyed in Berlin				
5.3	Klarmann	Wiss.Veroff S.K. 1939		Research worker on non-linear resistors for Siemens.				
5.4	Rother	C.I.O.S. XXXI - 22, XXIX - 48; Elect. Int. Rep. 41/45; A.L. No. 15 Sheet 15.		A research worker in ceramics, with some experience of semi-conductivity				X

Figure B.308: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

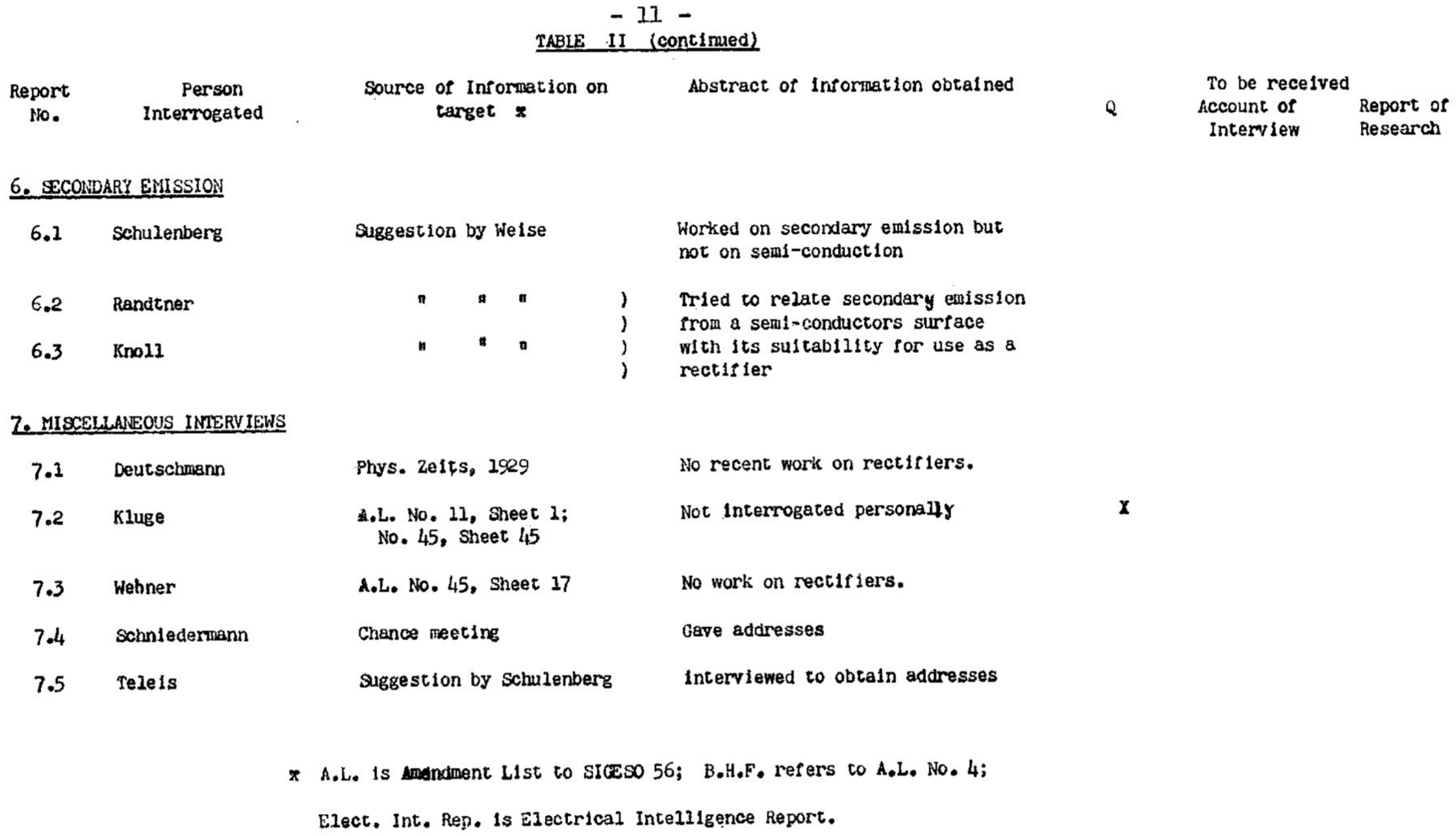

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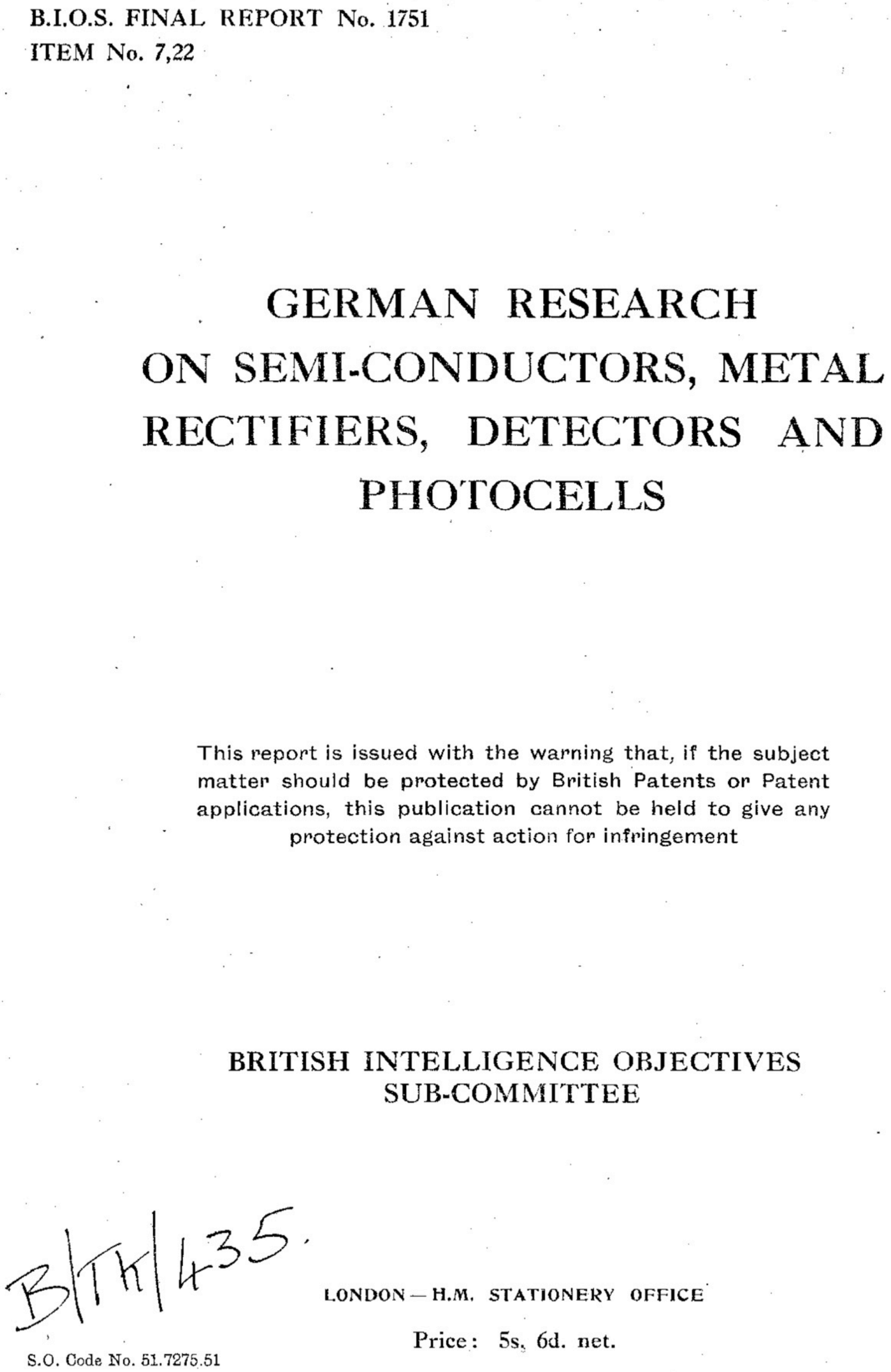
TABLE II (continued)

Report No.	Person Interrogated	Source of Information on target ⁎	Abstract of information obtained	Q	To be received Account of Interview	Report of Research
6. SECONDARY EMISSION						
6.1	Schulenberg	Suggestion by Weise	Worked on secondary emission but not on semi-conduction			
6.2	Randtner	" " ")	Tried to relate secondary emission from a semi-conductors surface with its suitability for use as a rectifier			
6.3	Knoll	" " ")				
7. MISCELLANEOUS INTERVIEWS						
7.1	Deutschmann	Phys. Zeits, 1929	No recent work on rectifiers.			
7.2	Kluge	A.L. No. 11, Sheet 1; No. 45, Sheet 45	Not interrogated personally	X		
7.3	Wehner	A.L. No. 45, Sheet 17	No work on rectifiers.			
7.4	Schniedermann	Chance meeting	Gave addresses			
7.5	Teleis	Suggestion by Schulenberg	interviewed to obtain addresses			

⁎ A.L. is Amendment List to SIGESO 56; B.H.F. refers to A.L. No. 4;

Elect. Int. Rep. is Electrical Intelligence Report.

Figure B.309: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 725]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



B.I.O.S. FINAL REPORT No. 1751
ITEM No. 7,22

GERMAN RESEARCH ON SEMI-CONDUCTORS, METAL RECTIFIERS, DETECTORS AND PHOTOCELLS

This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON — H.M. STATIONERY OFFICE

Price: 5s. 6d. net.

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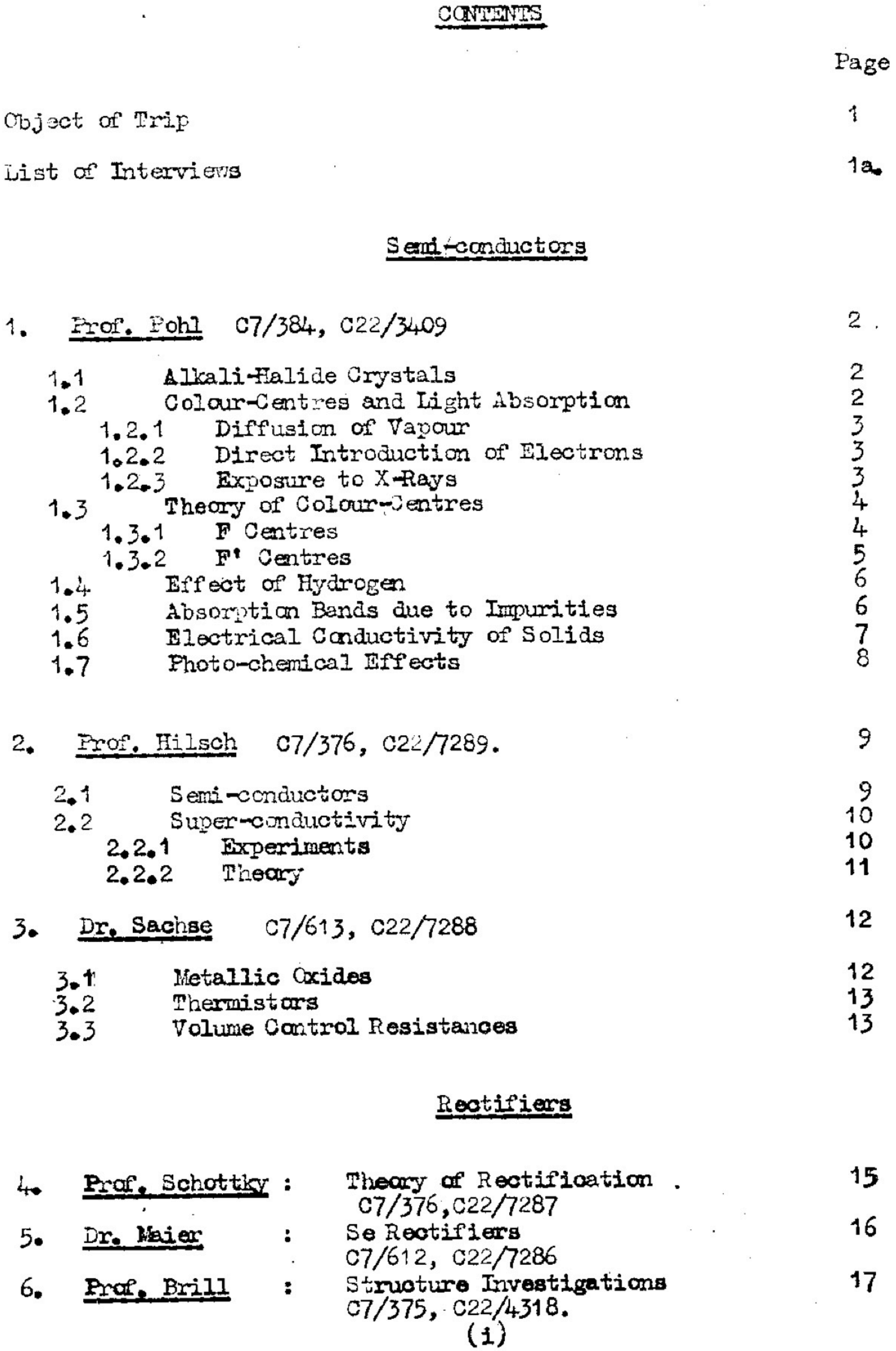
Figure B.310: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 1751]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



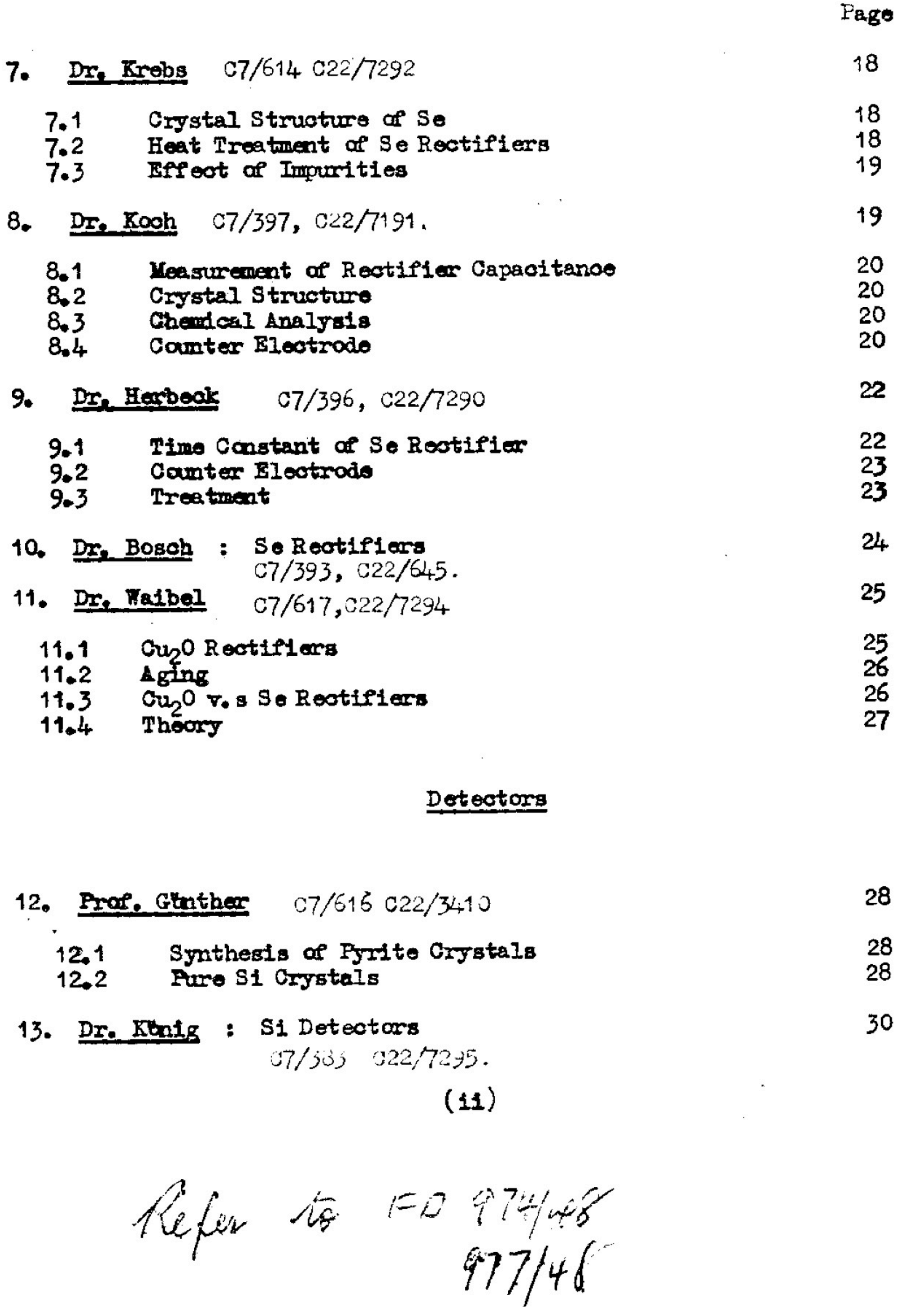
CONTENTS

Semi-conductors

Rectifiers

(i)

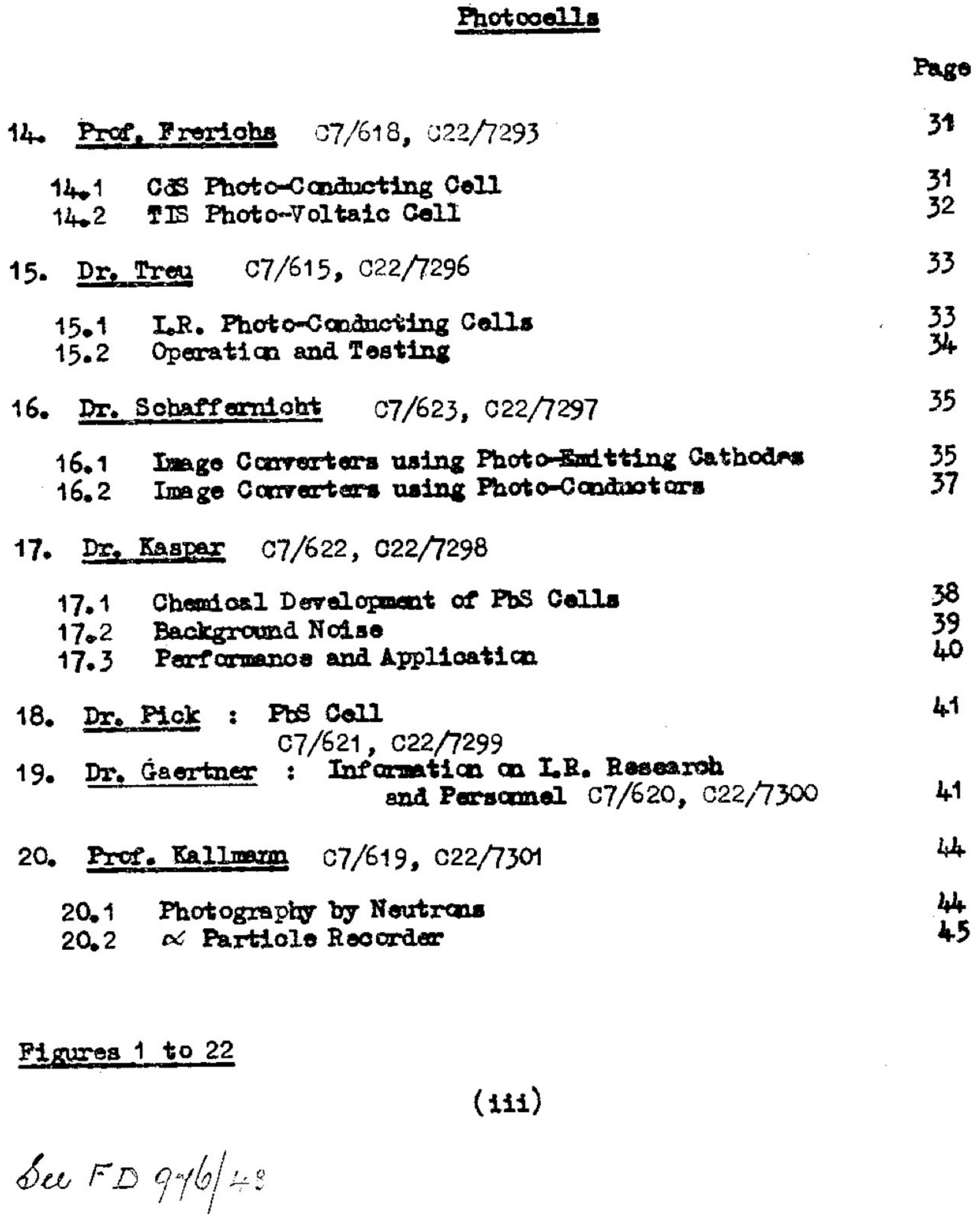
Figure B.311: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 1751]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



(ii)

Refer to FO 974/48
977/48

Figure B.312: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 1751]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

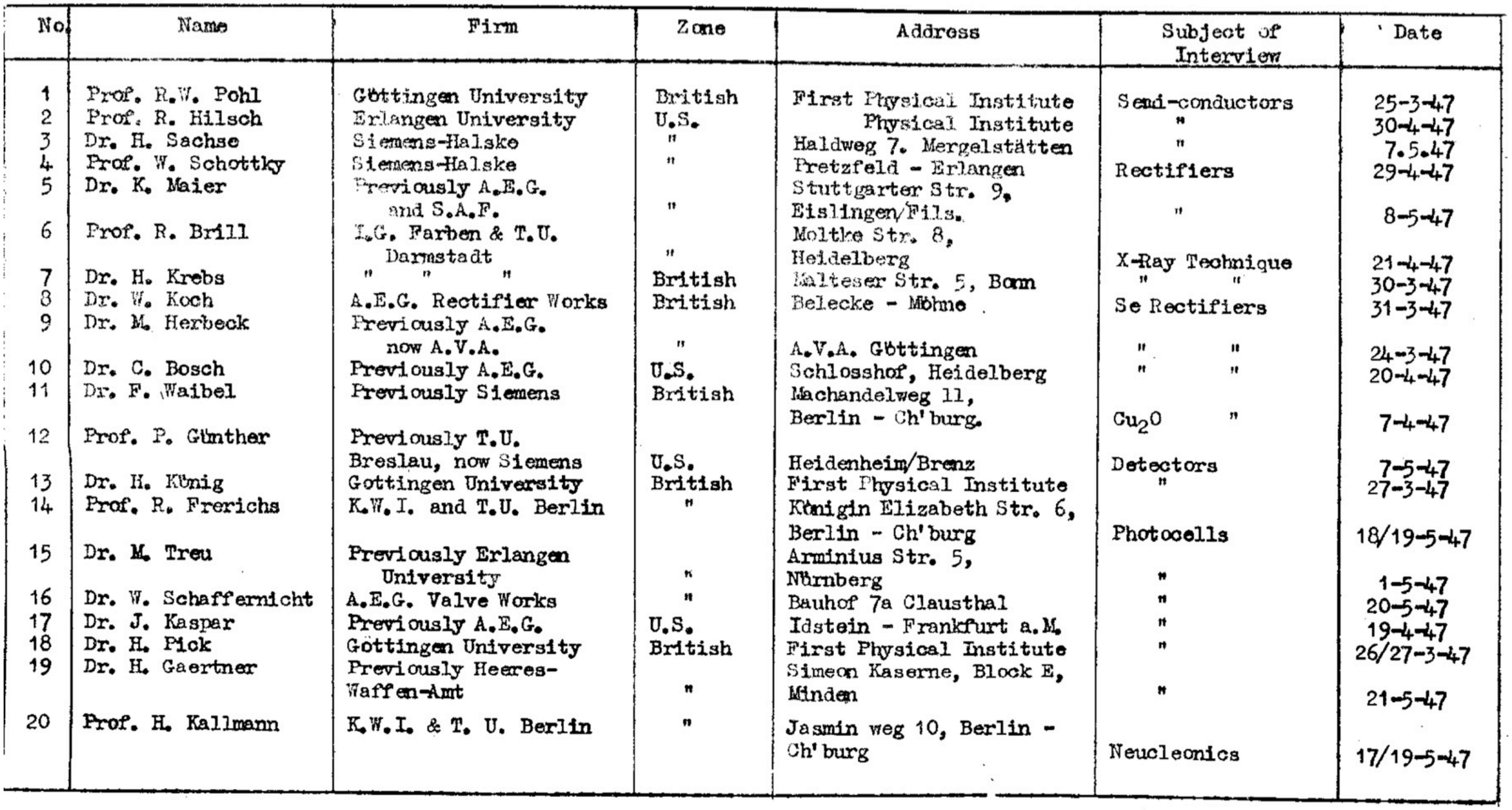


Photocells

(iii)

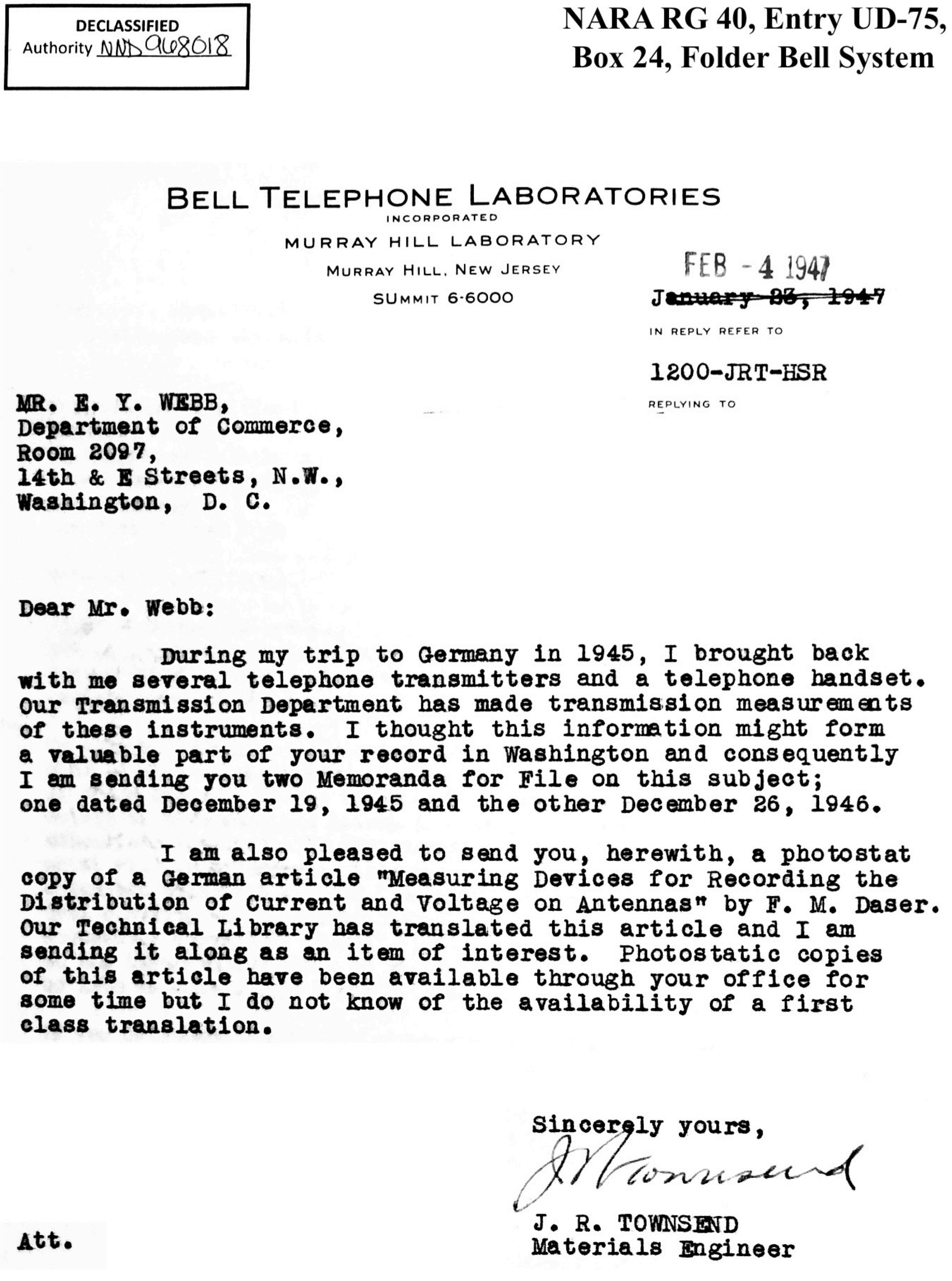
See FD 976/48

Figure B.313: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 1751]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



No.	Name	Firm	Zone	Address	Subject of Interview	Date
1	Prof. R.W. Pohl	Göttingen University	British	First Physical Institute	Semi-conductors	25-3-47
2	Prof. R. Hilsch	Erlangen University	U.S.	Physical Institute	"	30-4-47
3	Dr. H. Sachse	Siemens-Halske	"	Haldweg 7. Mergelstätten	"	7.5.47
4	Prof. W. Schottky	Siemens-Halske	"	Pretzfeld - Erlangen	Rectifiers	29-4-47
5	Dr. K. Maier	Previously A.E.G. and S.A.F.	"	Stuttgarter Str. 9, Eislingen/Fils.	"	8-5-47
6	Prof. R. Brill	I.G. Farben & T.U. Darmstadt	"	Moltke Str. 8, Heidelberg	X-Ray Technique	21-4-47
7	Dr. H. Krebs	" " "	British	Malteser Str. 5, Bonn	" "	30-3-47
8	Dr. W. Koch	A.E.G. Rectifier Works	British	Belecke - Möhne	Se Rectifiers	31-3-47
9	Dr. M. Herbeck	Previously A.E.G. now A.V.A.	"	A.V.A. Göttingen	" "	24-3-47
10	Dr. C. Bosch	Previously A.E.G.	U.S.	Schlosshof, Heidelberg	" "	20-4-47
11	Dr. F. Waibel	Previously Siemens	British	Machandelweg 11, Berlin - Ch'burg.	Cu_2O "	7-4-47
12	Prof. P. Günther	Previously T.U. Breslau, now Siemens	U.S.	Heidenheim/Brenz	Detectors	7-5-47
13	Dr. H. König	Gottingen University	British	First Physical Institute	"	27-3-47
14	Prof. R. Frerichs	K.W.I. and T.U. Berlin	"	Königin Elizabeth Str. 6, Berlin - Ch'burg	Photocells	18/19-5-47
15	Dr. M. Treu	Previously Erlangen University	"	Arminius Str. 5, Nürnberg	"	1-5-47
16	Dr. W. Schaffernicht	A.E.G. Valve Works	"	Bauhof 7a Clausthal	"	20-5-47
17	Dr. J. Kaspar	Previously A.E.G.	U.S.	Idstein - Frankfurt a.M.	"	19-4-47
18	Dr. H. Pick	Göttingen University	British	First Physical Institute	"	26/27-3-47
19	Dr. H. Gaertner	Previously Heeres-Waffen-Amt	"	Simeon Kaserne, Block E, Minden	"	21-5-47
20	Prof. H. Kallmann	K.W.I. & T. U. Berlin	"	Jasmin weg 10, Berlin - Ch'burg	Neucleonics	17/19-5-47

Figure B.314: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [BIOS 1751]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

BELL TELEPHONE LABORATORIES
INCORPORATED
MURRAY HILL LABORATORY
MURRAY HILL, NEW JERSEY
SUMMIT 6-6000

FEB - 4 1947
~~January 23, 1947~~

IN REPLY REFER TO
1200-JRT-HSR
REPLYING TO

MR. E. Y. WEBB,
Department of Commerce,
Room 2097,
14th & E Streets, N.W.,
Washington, D. C.

Dear Mr. Webb:

During my trip to Germany in 1945, I brought back with me several telephone transmitters and a telephone handset. Our Transmission Department has made transmission measurements of these instruments. I thought this information might form a valuable part of your record in Washington and consequently I am sending you two Memoranda for File on this subject; one dated December 19, 1945 and the other December 26, 1946.

I am also pleased to send you, herewith, a photostat copy of a German article "Measuring Devices for Recording the Distribution of Current and Voltage on Antennas" by F. M. Daser. Our Technical Library has translated this article and I am sending it along as an item of interest. Photostatic copies of this article have been available through your office for some time but I do not know of the availability of a first class translation.

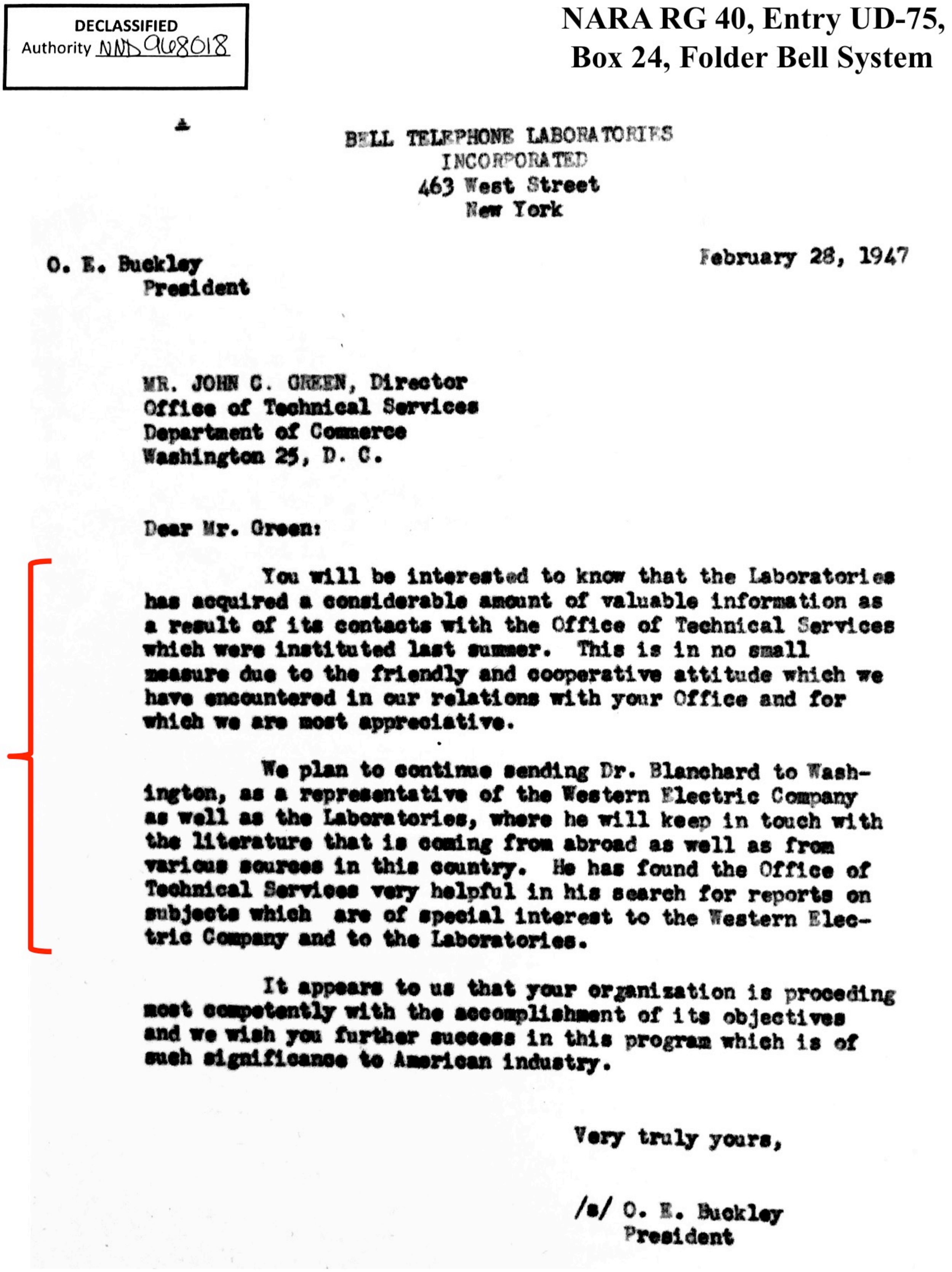
Sincerely yours,

J R Townsend

J. R. TOWNSEND
Materials Engineer

Att.

Figure B.315: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND968018

**NARA RG 40, Entry UD-75,
Box 24, Folder Bell System**

BELL TELEPHONE LABORATORIES
INCORPORATED
463 West Street
New York

February 28, 1947

O. E. Buckley
President

MR. JOHN C. GREEN, Director
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Dear Mr. Green:

You will be interested to know that the Laboratories has acquired a considerable amount of valuable information as a result of its contacts with the Office of Technical Services which were instituted last summer. This is in no small measure due to the friendly and cooperative attitude which we have encountered in our relations with your Office and for which we are most appreciative.

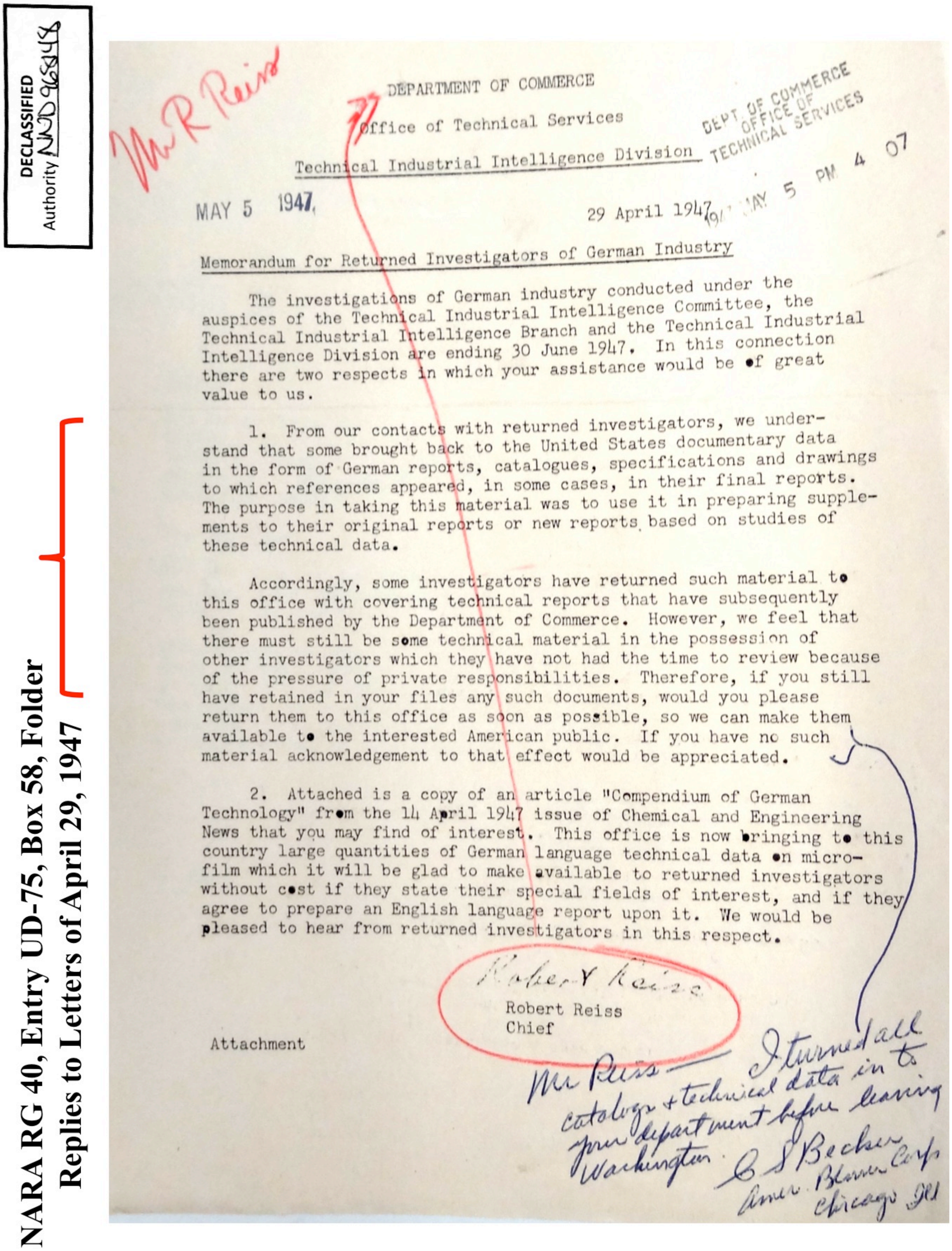
We plan to continue sending Dr. Blanchard to Washington, as a representative of the Western Electric Company as well as the Laboratories, where he will keep in touch with the literature that is coming from abroad as well as from various sources in this country. He has found the Office of Technical Services very helpful in his search for reports on subjects which are of special interest to the Western Electric Company and to the Laboratories.

It appears to us that your organization is proceding most competently with the accomplishment of its objectives and we wish you further success in this program which is of such significance to American industry.

Very truly yours,

/s/ O. E. Buckley
President

Figure B.316: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder
Replies to Letters of April 29, 1947

Mr Reiss

DEPARTMENT OF COMMERCE

Office of Technical Services

Technical Industrial Intelligence Division

DEPT OF COMMERCE
OFFICE OF
TECHNICAL SERVICES
1947 MAY 5 PM 4 07

MAY 5 1947

29 April 1947

Memorandum for Returned Investigators of German Industry

The investigations of German industry conducted under the auspices of the Technical Industrial Intelligence Committee, the Technical Industrial Intelligence Branch and the Technical Industrial Intelligence Division are ending 30 June 1947. In this connection there are two respects in which your assistance would be of great value to us.

1. From our contacts with returned investigators, we understand that some brought back to the United States documentary data in the form of German reports, catalogues, specifications and drawings to which references appeared, in some cases, in their final reports. The purpose in taking this material was to use it in preparing supplements to their original reports or new reports based on studies of these technical data.

Accordingly, some investigators have returned such material to this office with covering technical reports that have subsequently been published by the Department of Commerce. However, we feel that there must still be some technical material in the possession of other investigators which they have not had the time to review because of the pressure of private responsibilities. Therefore, if you still have retained in your files any such documents, would you please return them to this office as soon as possible, so we can make them available to the interested American public. If you have no such material acknowledgement to that effect would be appreciated.

2. Attached is a copy of an article "Compendium of German Technology" from the 14 April 1947 issue of Chemical and Engineering News that you may find of interest. This office is now bringing to this country large quantities of German language technical data on microfilm which it will be glad to make available to returned investigators without cost if they state their special fields of interest, and if they agree to prepare an English language report upon it. We would be pleased to hear from returned investigators in this respect.

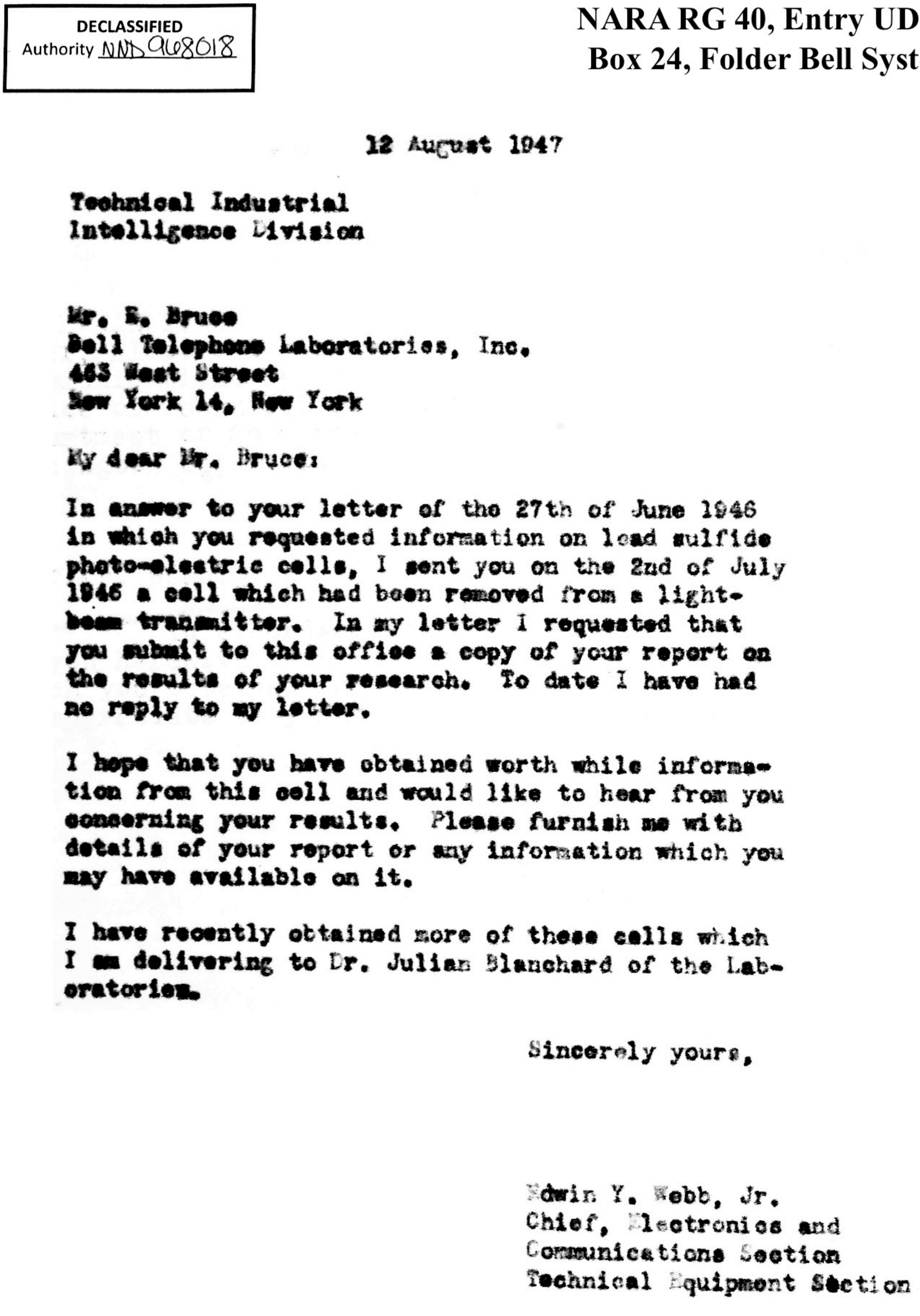
Robert Reiss

Robert Reiss
Chief

Attachment

Mr Reiss — I turned all catalogs + technical data in to your department before leaving Washington. C S Becker
Amer. Bloomer Corp
Chicago Ill

Figure B.317: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder Replies to Letters of April 29, 1947]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



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Authority NND 968018

NARA RG 40, Entry UD-75,
Box 24, Folder Bell System

12 August 1947

Technical Industrial
Intelligence Division

Mr. E. Bruce
Bell Telephone Laboratories, Inc.
463 West Street
New York 14, New York

My dear Mr. Bruce:

In answer to your letter of the 27th of June 1946 in which you requested information on lead sulfide photo-electric cells, I sent you on the 2nd of July 1946 a cell which had been removed from a light-beam transmitter. In my letter I requested that you submit to this office a copy of your report on the results of your research. To date I have had no reply to my letter.

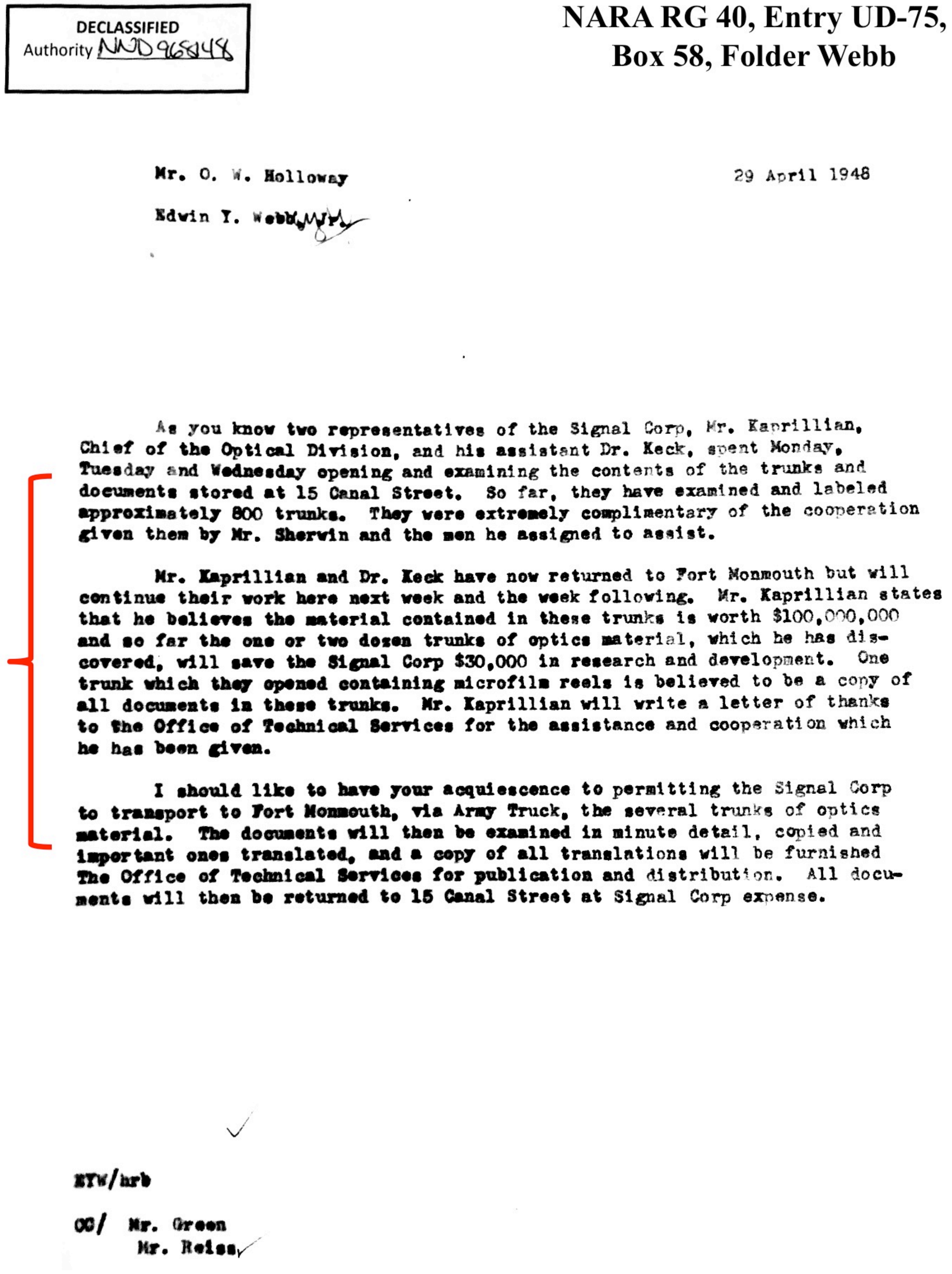
I hope that you have obtained worth while information from this cell and would like to hear from you concerning your results. Please furnish me with details of your report or any information which you may have available on it.

I have recently obtained more of these cells which I am delivering to Dr. Julian Blanchard of the Laboratories.

Sincerely yours,

Edwin Y. Webb, Jr.
Chief, Electronics and
Communications Section
Technical Equipment Section

Figure B.318: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 24, Folder Bell System]. There was likely a great deal of additional technology transfer that was not recorded in official documents.



DECLASSIFIED
Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder Webb

Mr. O. W. Holloway

29 April 1948

Edwin Y. Webb

As you know two representatives of the Signal Corp, Mr. Kaprillian, Chief of the Optical Division, and his assistant Dr. Keck, spent Monday, Tuesday and Wednesday opening and examining the contents of the trunks and documents stored at 15 Canal Street. So far, they have examined and labeled approximately 800 trunks. They were extremely complimentary of the cooperation given them by Mr. Sherwin and the men he assigned to assist.

Mr. Kaprillian and Dr. Keck have now returned to Fort Monmouth but will continue their work here next week and the week following. Mr. Kaprillian states that he believes the material contained in these trunks is worth $100,000,000 and so far the one or two dozen trunks of optics material, which he has discovered, will save the Signal Corp $30,000 in research and development. One trunk which they opened containing microfilm reels is believed to be a copy of all documents in these trunks. Mr. Kaprillian will write a letter of thanks to the Office of Technical Services for the assistance and cooperation which he has been given.

I should like to have your acquiescence to permitting the Signal Corp to transport to Fort Monmouth, via Army Truck, the several trunks of optics material. The documents will then be examined in minute detail, copied and important ones translated, and a copy of all translations will be furnished The Office of Technical Services for publication and distribution. All documents will then be returned to 15 Canal Street at Signal Corp expense.

EYW/hrb

CC/ Mr. Green
Mr. Reiss

Figure B.319: Example of archival documents demonstrating the postwar transfer of microelectronics documents, hardware, personnel, and knowledge [NARA RG 40, Entry UD-75, Box 58, Folder Webb]. There was likely a great deal of additional technology transfer that was not recorded in official documents.

Florian Metzler. 2020. The Transistor, an Emerging Invention: Bell Labs as a Systems Integrator Rather Than a 'House of Magic.' p. 33. https://ssrn.com/abstract=3678081

Karl Darrows, trained as a PhD physicist and a speaker of multiple languages, maintained personal relationships with a large number of leading academic physicists in Europe and the United States. European-trained researchers fulfilled similar tasks such as Foster Nix who received his graduate training in Berlin and was bilingual in English and German (Nix 1975). Relevant scientific news that Bell Labs employees such as Darrows and colleagues might have missed, were often brought to their attention by collaborators in Bell Labs' extended network. An example is Karl Lark-Horovitz, physics department head at Purdue and an Austrian immigrant, who regularly monitored German-language publications and drew attention to relevant new developments in interactions with Bell Labs collaborators (Van Dormael 2004).

Michael Eckert and Helmut Schubert. 1990. *Crystals, Electrons, Transistors: From Scholar's Study to Industrial Research.* pp. 158–163, 166

Bell Laboratories' research director Kelly was giving particular attention to applications in the field of radio for commercial exploitation after the war, once the field of microwaves and radio waves had been opened up to his organization through the radar project. [...] The physical research division was reorganized in July 1945 in order to give more emphasis to solid-state physics. [...]

Shockley, who returned to Bell Laboratories from his war service at the Pentagon in 1945, took charge of the semiconductor group as a theoretical solid-state physicist. The rest of this group consisted of the experimental physicist Brattain, who had been studying the properties of semiconductive surfaces since 1931; Pearson, also an experimental physicist, who had spent many years studying the interior properties of semiconductors; Hilbert Moore, a specialist in electronic circuits; and Robert Gibney, an expert in physical chemistry. To round out his team Shockley suggested to his superior Mr. Kelly that a position be offered to John Bardeen. Bardeen had earned his doctorate at Princeton under Wigner and had worked with van Vleck at Harvard, where Shockley had met him. Both Wigner and van Vleck were among the leading theoreticians in the field of solid-state physics. The general charter of the newly formed group called for the development of fundamental knowledge on the properties of semiconductors, but everyone had "in the back of his mind the objective of building an amplifier out of semiconductive material."

The semiconductor group at Bell Laboratories began its work with a survey of wartime developments in the field of semiconductors in their own research laboratories and those of others. [...]

Shockley could not patent the idea [of a field effect transistor], however, since Julius Lilienfeld had applied for a patent in 1926 on a very similar process, which, however, was never put to practical use. The experiments, however, in which Brattain collaborated, could not demonstrate the predicted effect. [...]

A decisive series of experiments began in November 1947. [...] On November 23, 1947, Bardeen wrote in his laboratory notebook that it was possible to amplify the flow of current from the electron-conducting layer into the metal wire tip by applying a voltage between the drop and the block of silicon. But no change occurred in the voltage between the block and the wire tip. This design, of course, was still entirely unsuitable for practical application. The drop of water evaporated quickly and only slowly changing currents were amplified. [...]

The further experiments in December 1947 were concentrated on the point contact. Bardeen reckoned that a significant amplification would be achieved when the contacts were spaced only some 0.05 mm apart. At that time this was a very difficult problem, which Brattain solved elegantly. He applied gold foil to a three-dimensional prism and cut it on one side of the triangle carefully with a razor blade in order to obtain two closely spaced contacts. This arrangement worked on the first try on December 16, 1947. It amplified signals up to 100 times, and amplification occurred even at frequencies in the radio wave region. A step had been made toward Kelly's research objective in the 1930s, the development of a practical solid-state repeater. A week of intensive work followed to make sure that no errors crept in. On December 23, 1947, the amplifier was shown to management. [...]

When the first germanium point-contact transistors were produced on an industrial scale in 1951 by Western Electric, the manufacturing arm of the Bell System, several other large firms were experimenting with the new component. It turned out to be difficult to build reliable transistors with the two closely space points, and it was almost impossible to produce them with identical characteristics. They had a very limited lifetime and could not process high-frequency currents. Compared with equivalent technical data for amplifier tubes, these transistors were not attractive products.

Jon Gertner. 2012. *The Idea Factory: Bell Labs and the Great Age of American Innovation.* pp. 90–92.

“My calculations showed that very substantial modulation of the resistance should occur,” Shockley later noted. “None was observed. On 23 June 1945, I wrote that the effects were at least 1,500 times smaller than what I predicted should have been observable.” He was vexed. And for close to a year, any attempts to make the field effect work failed. Shockley would eventually call this period “the natural blundering process of finding one’s way.”

Whatever it was, by January 1946 the solid-state group, venturing far beyond the traditional methods of trial-and-error invention, had found neither enlightenment nor promise. As Brattain’s lab mate Gerald Pearson would later note, they were groping in the dark. [...]

Shockley and Bardeen had even spent several weeks together in the summer of 1947 visiting various European laboratories. By late autumn, with the newly planted trees on the Murray Hill campus nearly bereft of leaves, the solid-state team began an experimental regimen on silicon and germanium slices that offered a steady progression of insights.

Lillian Hoddeson and Vicki Daitch. 2002. *True Genius: The Life and Science on John Bardeen.* pp. 128–131.

The group tried many related experiments, but for the next eighteen months they made little progress.

During the remainder of 1946 and throughout 1947, Shockley’s engagement with the field effect studies flagged, for he developed new interests during the summer of 1947, when he and Bardeen took an extended tour of European laboratories. [...]

Bardeen wrote that he had “learned a lot during the trip, and have picked up some information that may be useful to the Lab. Whether or not it’s enough to pay for the trip is hard to judge.” In any case, it had been “very hard work—much harder than you can imagine without doing it—but it’s also been a grand experience.” [...]

The “magic month” that culminated in the transistor began in the middle of November 1947, three months after Bardeen and Shockley returned from Europe.

Werner Grothmann (Heinrich Himmler's adjutant) [Krotzky 2002, p. 48]. For a discussion of the background and reliability of this source, see pp. 3396–3397.

Entweder steuert jemand die Rakete ins Ziel, oder die muß vollautomatisch gehen. Himmler war skeptisch, ob ein Pilot bei der Geschwindigkeit überhaupt reagieren kann. Ich meine, die Rakete sollte ja mit etlichen Tausend Kilometern fliegen. Dann gab es auch gar keine Fernsteuerung, die auf die Entfernung wirklich sicher funktionierte. Da hatte Himmler schon früher mal mit Ohnesorge darüber gesprochen und ich glaube, der hat dazu auch was arbeiten lassen. Was sich da ergeben hat, weiß ich aber nicht. Nur an eines kann ich mich noch erinnern, nämlich unsere Raketenleute hatten ja eine kleine Abteilung von, heute müsste sagen Elektronikern, die haben zur völligen Überraschung von uns und auch von Ohnesorge im Winter 44 eine Sende- und Empfangsanlage entwickelt, die man nicht mehr stören konnte, weil sie selbständig dauernd die Funkfrequenz änderte. Außerdem war die ganz klein, richtig winzig. Die hatte nur ungefähr ein kg, der Empfänger meine ich. Wie die das geschafft haben, diese Technik zu verkleinem, ist mir unbekannt. Himmler aber Befehl gegeben, Ohnesorge den Prototyp zu zeigen. Ob das geschehen ist, kann ich nicht sagen. Ich weiß auch nicht, ob der Sender überhaupt auf die Reichweite bis Amerika ausgelegt war. Nach Krieg hörten wir dann, die Amerikaner hätten den Transistor erfunden. Das hat wohl einige von unseren Leuten sehr aufgeregt, weil der doch von uns stammte. Ein Bekannter sagte mir dazu, bei uns hätte der Transistor "Sperrschicht-Halbleiter" geheißen. Der war von einem Professor an einer technischen Hochschule erfunden worden. Es kann sein das war Aachen.

Either someone pilots the rocket into the target, or it must be fully automatic. Himmler was skeptical whether a pilot could react at all at that speed. I mean, the rocket was supposed to fly several thousand kilometers. Then there was no remote control at all, which really worked safely at that distance. Himmler had already talked to Ohnesorge about this and I think he had something worked out. But I don't know what came of it. I can only remember one thing, namely that our rocket people had a small department of, today I would have to say electronic engineers, who, to the complete surprise of us and also of Ohnesorge, developed a transmitting and receiving system in the winter of 44, which could no longer be jammed, because it constantly changed the radio frequency on its own. It was also very small, really tiny. It weighed only about one kilogram, the receiver I mean. How they managed to miniaturize this technology is unknown to me. But Himmler gave orders to show the prototype to Ohnesorge. Whether this was done, I cannot say. I also don't know if the transmitter was even designed to reach America. After the war, we heard that the Americans had invented the transistor. That must have upset some of our people very much, because it came from us. An acquaintance told me that in our country the transistor was called a "junction semiconductor." It had been invented by a professor at a technical university. It may have been Aachen.

[For other sources that confirmed that highly advanced electronic guidance systems for long-range missiles were developed in Germany during the war and then transferred after the war to the United States, specifically AT&T Bell Laboratories, see for example pp. 2938–2962, 5348, 5444, 5454, 5557.

Evidence such as that presented in this appendix suggests (but does not yet prove—much more investigation is required) that the German-speaking scientists' transistor developments not only preceded those of Bell Laboratories, but may have been directly used by Bell Laboratories as a guide to reproduce the earlier German-speaking work:

- The German-speaking transistor developments came from at least 12 different groups doing extensive work during a period of over two decades collectively.

- During World War II, the German military was keenly interested in funding the development of smaller, more rugged, and more sophisticated electronic guidance systems that could be used in rockets ranging from anti-aircraft missiles to intercontinental ballistic missiles. Transistors derived from the existing German patents and papers would have been an important part of those guidance systems.

- In spring 1945, hundreds of thousands of tons of German-language technical documents were seized by the United States, thousands of German-speaking scientists were interrogated by U.S. scientists and engineers, and countless prototypes, pieces of equipment, and whole laboratories were shipped to the United States.

- Personnel from Bell Laboratories played a prominent role in collecting that scientific information from Europe and processing it in the United States.

- In late 1945, Bell Laboratories put John Bardeen and Walter Brattain to work to try to produce a simple transistor, with some supervision by William Shockley. As noted above, “the semiconductor group at Bell Laboratories began its work with a survey of wartime developments in the field of semiconductors.”

- Bardeen and Shockley conducted detailed visits to numerous European laboratories from June through August 1947. During that time, Bardeen or Shockley could have easily encountered scientists, reports, or information from the earlier transistor development programs of the German-speaking world, or at least Allied investigators who had already studied those programs. Although any transistor-related information that Bardeen and Shockley learned during this time has never been publicly disclosed, Bardeen wrote at the end of the trip: “learned a lot during the trip, and have picked up some information that may be useful to the Lab” [Hoddeson and Daitch 2002, p. 130].

- Bardeen and Brattain did not begin serious experimentation with transistor-like devices until November 1947, two and a half years after the end of the war (and over two and a half years after the collection and study of German microelectronics information began in earnest). Within just a couple of months this very small team created what appears to be a crude replica of the earlier German work.

- Not only did Shockley not give any credit to the earlier German work, but he refused to give proper credit to Bardeen and Brattain, who actually performed the Bell Laboratories experiments.

- Due to their personal differences, the team of Bardeen, Brattain, and Shockley soon split up. Even in 1951, Western Electric (the manufacturing arm of AT&T/Bell Laboratories) was unable to produce reliable transistors. Most transistor development in the United States was carried out by other researchers, including several German-speaking scientists (Kurt Lehovec, Herbert Kroemer, Jean Hoerni, Eugene Kleiner, Karl Heinz Zaininger, etc.) as shown in this appendix.

Much more archival research is needed to determine the true extent of microelectronics innovations in the German-speaking world, as well as how much that influenced postwar work in other countries.]