Chapter 6

Creators and Creations in Electrical and Electromagnetic Engineering

Nehmen Sie zum Beispiel dieses komische Rohr, das sie in Amsterdam verkaufen. Ich habe es genau untersucht. Eine Hülse aus grünem Leder und zwei Linsen, eine so—*er deutet eine konkave Linse an*—, eine so—*er deutet eine konvexe Linse an.* Ich höre, eine vergrößert und eine verkleinert. Jeder vernünftige Mensch würde denken, sie gleichen einander aus. Falsch. Man sieht alles fünfmal so groß durch das Ding. Das ist Ihre Wissenschaft.

You take for example that funny tube that they are selling in Amsterdam. I examined it closely. A casing of green leather and two lenses, one like that—*he indicates by gesture a concave lens*—, one like that—*he indicates a convex lens.* I hear that one enlarges and one reduces. Any sensible person would think that they would cancel each other out. Wrong. One sees everything five times as large through the thing. That is your science.

Bertolt Brecht. 1939. *Leben des Galilei* [*Life of Galileo*]. Scene 1. Ludovico.

This chapter gives an overview of some innovations in electrical and electromagnetic engineering that have played major roles in the modern world and that were invented or discovered by scientists and engineers who were trained in the predominantly German-speaking central European research world in the nineteenth and early twentieth centuries.

Creators from the German-speaking world made major contributions to:[1]

6.1. Electrical equipment and circuits

6.2. Lighting technology

6.3. Communications and recording technologies

6.4. Lasers and holography

6.5. Solid state physics and microelectronics

6.6. Infrared vision and targeting

6.7. Computers and robotics

6.8. Radar and sonar technologies and countermeasures

6.9. Optical microscopes, telescopes, and other optical instruments

6.10. Electron microscopes

[1]In addition to specific references that are cited in different areas throughout this chapter, this chapter makes use of general biographical and project information from: ACLS 2000; Albrecht et al. 1992; Ash and Söllner 1996; Bar-Zohar 1967; Bower 1987; Bunch and Hellemans 2004; Challoner 2009; Cornwell 2003; Crim 2018; EB 1911, 2010; Gillispie 1970–1990; Gimbel 1990a; Glatt 1994; Hall 2019a; István Hargittai 2006, 2011; Linda Hunt 1991; Impey et al. 2008; Jacobsen 2014; Koertge 2007; Kragh 2002; Kurowski 1982; Lasby 1971; Lusar 1956, 1971; Medawar and Pyke 2000; Mick 2000; Murray 2003; Nachmansohn 1979; NDB 1953–2020; Neufeld 2012; Nouzille and Huwart 1999; O'Reagan 2014, 2019; Porter 1994; Charles Walker 1946; Peter Watson 2010; Weitensfelder 2009.

For general overviews of large portions of the history of electrical and electromagnetic engineering in the German-speaking world, see: Buchheim and Sonnemann 1990; Bunch and Hellemans 2004 Cardwell 1995; Challoner 2009; Gerhart Göbel 1953; Gööck 2000; Heckl 2010, 2011; Heßler 2012; Hickethier 1998; Jankowsky 2000; König 2000, 2009; König and Schneider 2007; Ludwig 1974; Lundgreen and Grelon 1994; Radkau 1989, 2016; Technisches Museum Wien 2011; von Weiher 1983; Weitensfelder 2009, 2013; https://www.cdvandt.org; https://www.gfgf.org; https://www.radiomuseum.org.

I have deliberately left a blank space where images of some creators or creations should go. Those are people or projects that I felt were important enough that they should definitely be shown in this book, yet I have not yet been able to locate a suitable image that I have permission to use, despite my searches in Europe and in the United States. If readers have any relevant images and could send them to me, I would be very grateful and will include them in future editions of this book. Even where a suitable photo cannot be located, I believe that leaving a blank space pays tribute both to the scientific importance of that creator or creation and to how that historical fact has been very nearly forgotten.

To supplement this chapter, Appendix B provides examples of key documents on transistors, printed circuits and multi-pin connectors, integrated circuits, light emitting diodes (LEDs), etc. These documents demonstrate that German-speaking research groups invented, developed, and demonstrated those revolutionary microelectronics technologies many years before Bell Laboratories and other non-German firms claimed to have officially "invented" them. Moreover, the documents show numerous examples of how the relevant technical information was transferred from the German-speaking world to those firms.

Similarly, Appendix C provides considerable evidence for how directed energy technologies were developed within the German-speaking world and then transferred to other countries. Those directed energy technologies include not only lasers, but also particle beams and X-rays, electromagnetic pulse weapons, focused sound waves, and electromagnetic railguns.

Scientists from the German-speaking world also made numerous contributions to overlapping and related areas listed in other chapters, especially Chapter 5 (physics).

In September 1945, R. P. Linstead and T. J. Betts, the British and American chairs of the Combined Intelligence Objectives Subcommittee (CIOS), listed examples of several German innovations in electronics that would be copied by other countries [AFHRA A5186 electronic version pp. 904–1026, Ch. 4, pp. 38–40]:

> 1. The "Schornsteinfeger" project of radar camouflage is of definite interest. German scientists were discovered to have developed various types of anti-radar coverings which would prevent radar detection. These coverings were applied and used operationally in coating submarine "Schnorkels." Still further applications were contemplated by German experts engaged on this project.
>
> 2. Enemy development of Continuous Wave Transmission Navigational Aids was found to be well advanced. German equipment was capable of greater accuracy and greater range than any hitherto known. Fundamental research data was obtained concerning propagation conditions for use in CW Transmissions.
>
> 3. Infra-red development had received much attention by German experts, and their technique was in advance of that of the Allies. Infra-red was used for night vision to permit night driving of military vehicles, and night sighting and aiming of weapons under conditions of total black-out. Another application was in infra-red searchlights used for the protection of harbor entrances. An entire German combat element had been equipped with infra-red and trained in its use for employment on the Eastern front.
>
> 4. The design of polyrod aerials had been rejected as a development project by British and US authorities. It was discovered that the Germans had achieved successful use of this equipment in many applications. The polyrod aerial possesses important space saving advantages in centimetric radar work.
>
> 5. German scientists had conducted extensive ionospheric investigations. The bulk of their research data has been obtained by Allied scientists.
>
> 6. The enemy had achieved much in the development of materials with a wide range of

> electrical and magnetic properties, and of materials which become superconducting at relatively high temperatures.
>
> 7. Investigation revealed that German radio valve design was generally less advanced than our own. However, particular types of special valve designs have proven of interest.
>
> 8. German electron microscopes, capable of a magnification of 200,000 times, while not more advanced than our own, yield new information of interest.
>
> 9. Examination of anti-jamming circuits used by the Germans has provided new information.
>
> 10. Much valuable information on the use of electronic control and telemetering equipment in guided missiles of all kinds has been obtained.
>
> American experts discovered the Bosch machine and control equipment used for the manufacture of a new type of paper capacitors (condensers). Condensers produced by this process have important advantages over the types generally used in the US and United Kingdom. They are designed with a self-healing feature which will overcome repeated breakdowns resulting from over-voltage surges. One complete unit of this manufacturing equipment has been obtained for evacuation to the US.

In addition to large numbers of government reports, journalists also documented that many revolutionary electronic technologies were transferred out of the German-speaking world after World War II. For example, in October 1946, *Harper's Magazine* reported [Charles Walker 1946]:

> The head of the communications unit of Technical Industrial Intelligence Branch opened his desk drawer and took out the tiniest vacuum tube I had ever seen. It was about half thumb-size.
>
> *Notice it is heavy porcelain—not glass—and thus virtually indestructible. It is a thousand watt—one-tenth the size of similar American tubes. Today our manufacturers know the secret of making it. . . . And here's something. . . .*
>
> He pulled some brown, papery-looking ribbon off a spool. It was a quarter-inch wide, with a dull and a shiny side.
>
> "That's Magnetophone tape," he said. "It's plastic, metallized on one side with iron oxide. In Germany that supplanted phonograph recordings. A day's radio program can be magnetized on one reel. You can demagnetize it, wipe it off and put a new program on at any time. No needle; so absolutely no noise or record wear. An hour-long reel costs fifty cents." He showed me then what had been two of the most closely-guarded, technical secrets of the war: the infra-red device which the Germans invented for seeing at night, and the remarkable diminutive generator which operated it. German cars could drive at any speed in a total blackout, seeing objects clear as day two hundred meters ahead. Tanks with this device could spot targets two miles away. As a sniper scope it enabled German riflemen to pick off a man in total blackness.

There was a sighting tube, and a selenium screen out front. The screen caught the incoming infra-red light, which drove electrons from the selenium along the tube to another screen which was electrically charged and fluorescent. A visible image appeared on this screen. Its clearness and its accuracy for aiming purposes were phenomenal. Inside the tube, distortion of the stream of electrons by the earth's magnetism was even allowed for!

The diminutive generator—five inches across—stepped up current from an ordinary flashlight battery to 15,000 volts. It had a walnut-sized motor which spun a rotor at 10,000 rpm—so fast that originally it had destroyed all lubricants with the great amount of ozone it produced. The Germans had developed a new grease: chlorinated paraffin oil. The generator then ran 3,000 hours!

A canvas bag on the sniper's back housed the device. His rifle had two triggers. He pressed one for a few seconds to operate the generator and the scope. Then the other, to kill his man in the dark. "That captured secret," my guide declared, "we first used at Okinawa—to the bewilderment of the Japs."

We got, in addition, among these prize secrets, the technique and the machine for making the world's most remarkable electric condenser. Millions of condensers are essential to the radio and radar industry. Our condensers were always made of metal foil. This one is made of paper, coated with 1/250,000 of an inch of vaporized zinc. Forty per cent smaller, twenty per cent cheaper than our condensers, it is also self-healing. That is, if a breakdown occurs (like a fuse blowing out), the zinc film evaporates, the paper immediately insulates, and the condenser is right again. It keeps on working through multiple breakdowns—at fifty per cent higher voltage than our condensers! To most American radio experts this is magic, double-distilled.

6.1 Electrical Equipment and Circuits

Scientists from the predominantly German-speaking world led the discovery of electrical principles and the application of those principles to create essential types of electrical equipment and circuits.

Martinus van Marum (Dutch, 1750–1837) developed and experimented with electrostatic generators and discovered ozone (Fig. 6.1).

In 1820, Johann Schweigger (German states, 1779–1857) developed the galvanometer for measuring electric current. See Fig. 6.2.

Using galvanometers and different electrical conductors, Georg Ohm (German states, 1789–1854, Fig. 6.2) studied the electrical properties of simple circuits. He demonstrated that the voltage difference V across an electrical component depends on the current I through the component and the electrical resistance R of the component, in accordance with the equation $V = IR$, which is now known as Ohm's law. Oxford University's *Biographical Dictionary of Scientists* explained how Ohm arrived at his conclusions [Porter 1994, p. 390]:

> Ohm began the work that led him to his law of electricity in 1825. He investigated the amount of electromagnetic force produced in a wire carrying a current[...] Ohm found that a longer wire produced a greater loss in electromagnetic force. [...]
>
> From this, Ohm reached the more general statement that the current is equal to the tension (emf or potential difference) divided by the overall resistance of the circuit, thus expressing the law in the form known as Ohm's law.
>
> Ohm went on to use an electroscope to measure how the tension varied at different points along a conductor to verify his law, and presented his arguments in mathematical form in his great work of 1827. He made a useful analogy with the flow of heat through a conductor, pointing out that an electric current flows through a conductor of varying resistance from one tension or potential to another to produce a potential difference, just as heat flows through a conductor of varying conductivity from one temperature to another to produce a temperature difference. [...]
>
> Ohm's derivation of a basic law of nature from experiment was a classic piece of scientific deduction.

Andreas von Ettingshausen (Austrian, 1796–1878, Fig. 6.2) designed the first machine to use electromagnetic induction to generate power.

Heinrich Lenz (Baltic German, 1804–1865, Fig. 6.2) formulated what is now known as Lenz's law, which describes how a changing magnetic field induces electric currents in nearby conductors that create new magnetic fields opposing the changing field. He also discovered that the power P consumed by an electric circuit depends on the current I flowing through the circuit and the electrical resistance R of the circuit, $P = I^2R$.

Heinrich Rühmkorff (German, 1803–1877) developed improved magnetic induction coils, now called

Rühmkorff coils, and used them in a variety of applications such as AC transformers and high-voltage generators. See Fig. 6.3.

Werner von Siemens (German, 1816–1892, Figs. 6.4 and 6.23) began his career by creating more sophisticated telegraphs that could point to individual letters, and went on to invent and build a wide range of additional electrical innovations such as electric generators (dynamos), electric motors, transformers, electric elevators, and electric trains [Bähr 2016; von Siemens 1895]. The American Council of Learned Societies noted [ACLS 2000, p. 810]:

> First successful invention was an improved process for gold- and silverplating. After improving upon the indicator telegraph of Wheatstone, he developed an entire telegraph system; in 1847, together with Halske, he founded the Telegraphenbauanstalt von Siemens & Halske to manufacture and construct telegraph systems, eventually expanding to London, St. Petersburg, and Vienna. Helped design the first special cable-laying ship, the *Faraday*, and organized and constructed the Indo-European telegraph from London to Calcutta (1870). His most outstanding contribution was his discovery of the dynamo principle and its practical applications to streetcars and mine locomotives, in electrolysis, and in central generating stations.

Gustav Kirchhoff (German, 1824–1887) worked in many areas of physics, chemistry, and engineering (see also pp. 433, 605, 866, 923, and 966). He discovered a number of physical laws that now have his name attached to them, including laws illustrated in Fig. 6.5 that describe the current and voltage in electric circuits. Oxford University's *Biographical Dictionary of Scientists* summarized his contributions to electrical engineering and electromagnetism [Porter 1994, p. 390]:

> Kirchhoff made his first important contribution to physics while still a student. In 1845 and 1846 he extended Ohm's law to networks of conductors and derived the laws known as Kirchhoff's laws that determine the value of the current and potential at any point in a network. He went on to consider electrostatic charge and in 1849 showed that electrostatic potential is identical to tension, thus unifying static and current electricity. Kirchhoff made another fundamental discovery in electricity in 1857 by showing theoretically that an oscillating current is propagated in a conductor of zero resistance at the velocity of light. This was important in the development in the 1860s of the electromagnetic theory of light[...]

As shown in Fig. 6.6, Johann Sigmund Schuckert (German, 1846–1895) improved electric generators and motors, and also created some of the first lighting systems for streets and buildings in the 1870s. His company, Schuckert & Co., competed with the Siemens company to develop and sell new electrical products. After the deaths of their respective founders, the two companies merged.

František Křižík (Austrian/Czech, 1847–1941) created electric generators, electric motors, electric trains, electric cars, improved arc lamps, etc. (Fig. 6.7).[2] The company he founded, Krizik Works, continued to be an important high-tech industrial center during World War II and the postwar Soviet occupation of Czechoslovakia (e.g., pp. 4021–4032).

[2]https://czech-presidency.consilium.europa.eu/en/news/frantisek-krizik-the-inventor-who-illuminated-the-world-and-bohemia-with-arc-lamps/

Nikola Tesla (Serbo-Croatian, educated in Austria, 1856–1943) invented a complete AC (alternating current) electric power generation, distribution, and usage system for the Westinghouse company in the United States. He also created a wide range of other revolutionary electrical innovations [Cheney 1981; Cheney and Uth 1999; Tesla 1893, 1904, 1919, 1940]. See Fig. 6.8. Tesla biographer Margaret Cheney summed up his impact [Cheney and Uth 1999, pp. vi–vii]:

> Tesla is indisputably the father of alternating current power generation and transmission. His AC technology, first introduced on a large scale at Niagara Falls in 1896, remains unchanged and unchallenged to this day. The same holds true for Tesla's "Apparatus for Transmission of Electrical Energy," patented in 1900, which is still the basis for transmitting and receiving all radio and television signals. These two technologies alone merit the recognition and gratitude of every inhabitant on this planet.
>
> Like other great inventors, Tesla was a true Renaissance man. He turned fresh loam across half-a-dozen fields of science. He patented hundreds of inventions, crafted his own tools, built his own machines, practiced and consulted as an electrical engineer, handled his own press relations with dexterity and *élan*, and was even known to write poetry. Not only did this 19th-century polymath perform such heavy roles under one hat, he was also an environmentalist, a health and nutrition advocate, a philosopher, and many would say a visionary genius.
>
> Tesla was a "heroic" inventor—something we need more of today. He looked at invention as a way to improve the lot of mankind, not just a means of enhancing wealth, or meeting the demands of the marketplace. [...]
>
> Though few inventors have contributed more to the development of the United States as a world power, the prestigious Smithsonian Institution has never substantially acknowledged Tesla's contribution. His alternating current generator, for example, is included in the museum's exhibit on Thomas Edison. The Institution has also been reluctant to credit Tesla's critical role in the invention of radio even though the U.S. Supreme Court affirmed his patent priority over Marconi in 1943. [...]
>
> As a result of this historical bias, Tesla's major inventions are usually attributed to others. [...]
>
> Every time we turn on a light, or a radio, or operate a remote control we continue his legacy. His name should be respected everywhere electricity flows.

As illustrated in Fig. 6.9, Charles (Karl) Steinmetz (German, 1865–1923) invented a complete AC electric power generation, distribution, and usage system for the rival General Electric company in the United States. The *Encyclopedia Britannica* listed some of his key insights [EB 2010]:

> Steinmetz' experiments on power losses in the magnetic materials used in electrical machinery led to his first important work, the law of hysteresis. This law deals with the power loss that occurs in all electrical devices when magnetic action is converted to unusable heat. Until that time the power losses in motors, generators, transformers, and other electrically powered machines could be known only after they were built. Once

> Steinmetz had found the law governing hysteresis loss, engineers could calculate and minimize losses of electric power due to magnetism in their designs.
>
> His second contribution was a practical method for making calculations concerning alternating current circuits. This method was another example of using mathematical aids for engineering the design of machinery and power lines, so that the performance of the electrical system could be predicted in advance. This accomplishment was largely responsible for the rapid progress made in the commercial introduction of alternating-current apparatus. [...]
>
> Steinmetz' third major achievement was in the theory of electrical transients—that is, changes in electrical circuits of very short duration. A prime example of this phenomenon is lightning, and Steinmetz' investigation of lightning phenomena resulted in his theory of traveling waves and opened the way for his development of devices to protect high-power transmission lines from lightning bolts.

Brothers Wilhelm Emil Fein (German, 1842–1898) and Carl Fein (German, 18??–19??) invented the electric hand drill in 1895. See Fig. 6.10.

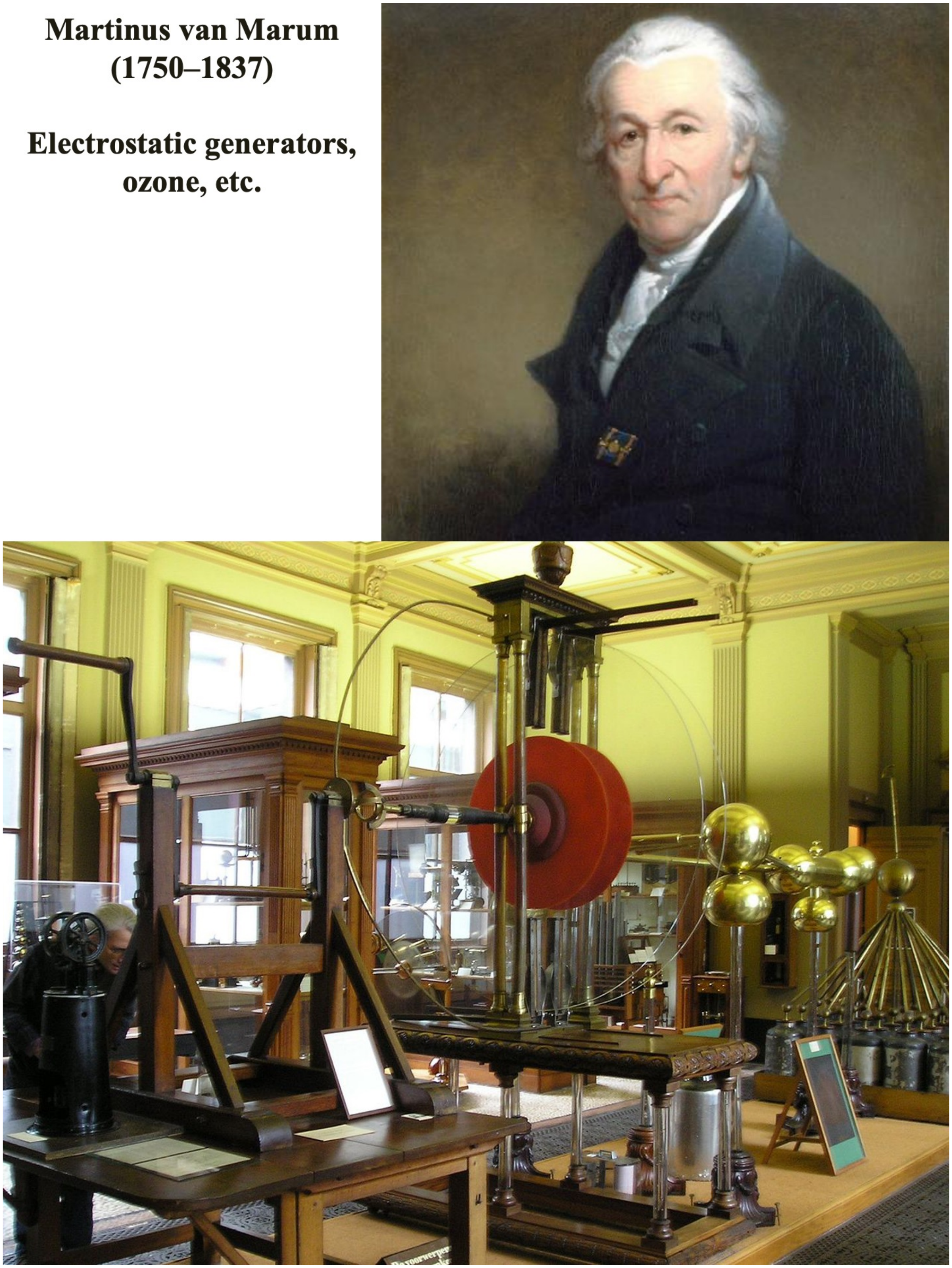


Figure 6.1: Martinus van Marum (Dutch, 1750–1837) developed and experimented with electrostatic generators and discovered ozone.

Figure 6.2: Johann Schweigger invented the galvanometer, Georg Ohm discovered Ohm's law, Andreas von Ettingshausen developed the electromagnetic induction generator, and Heinrich Emil Lenz discovered Lenz's law and the electric power law.

Heinrich Rühmkorff (1803–1877)
created AC transformers and electric generators

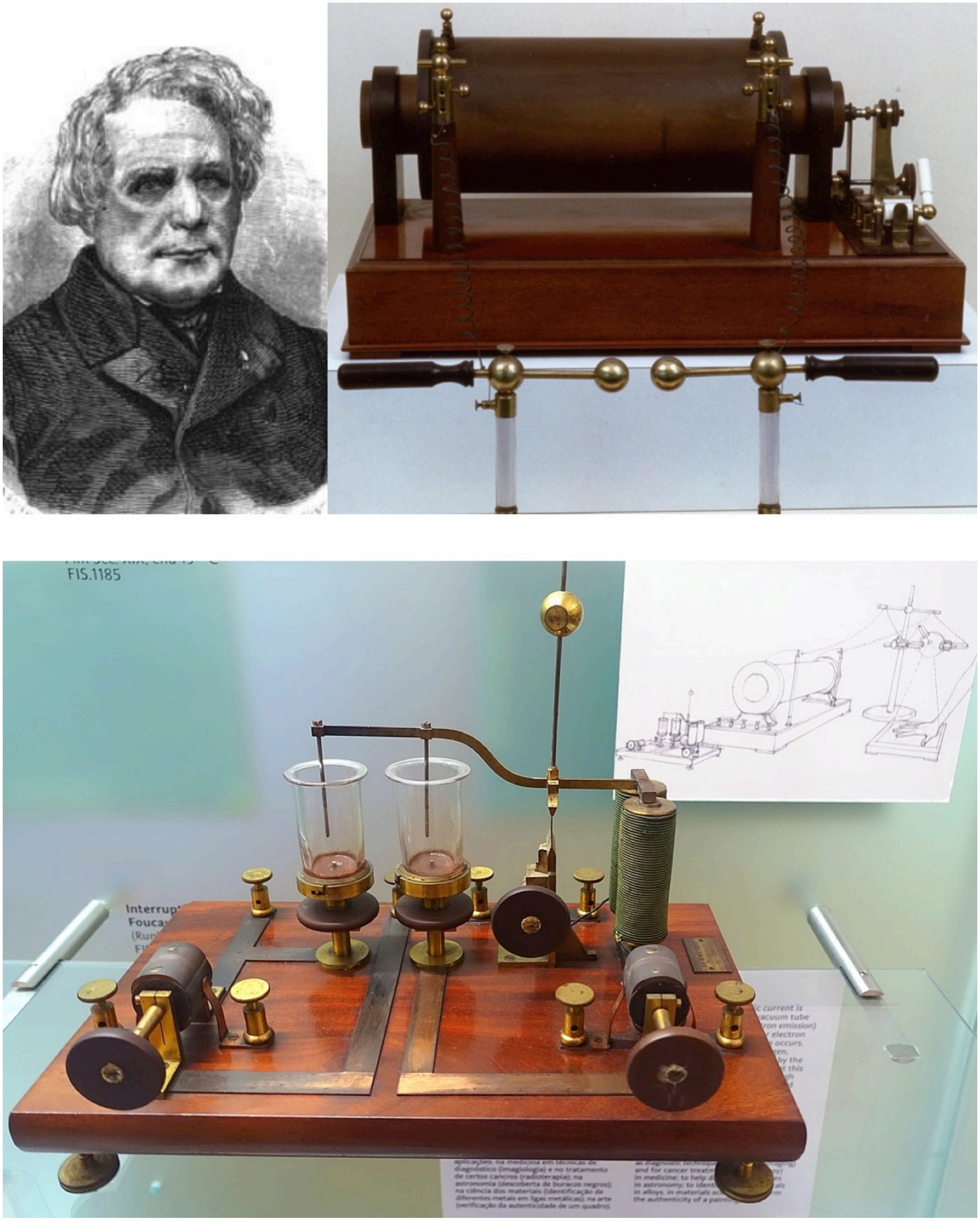


Figure 6.3: Heinrich Rühmkorff created AC transformers, electric generators, etc.

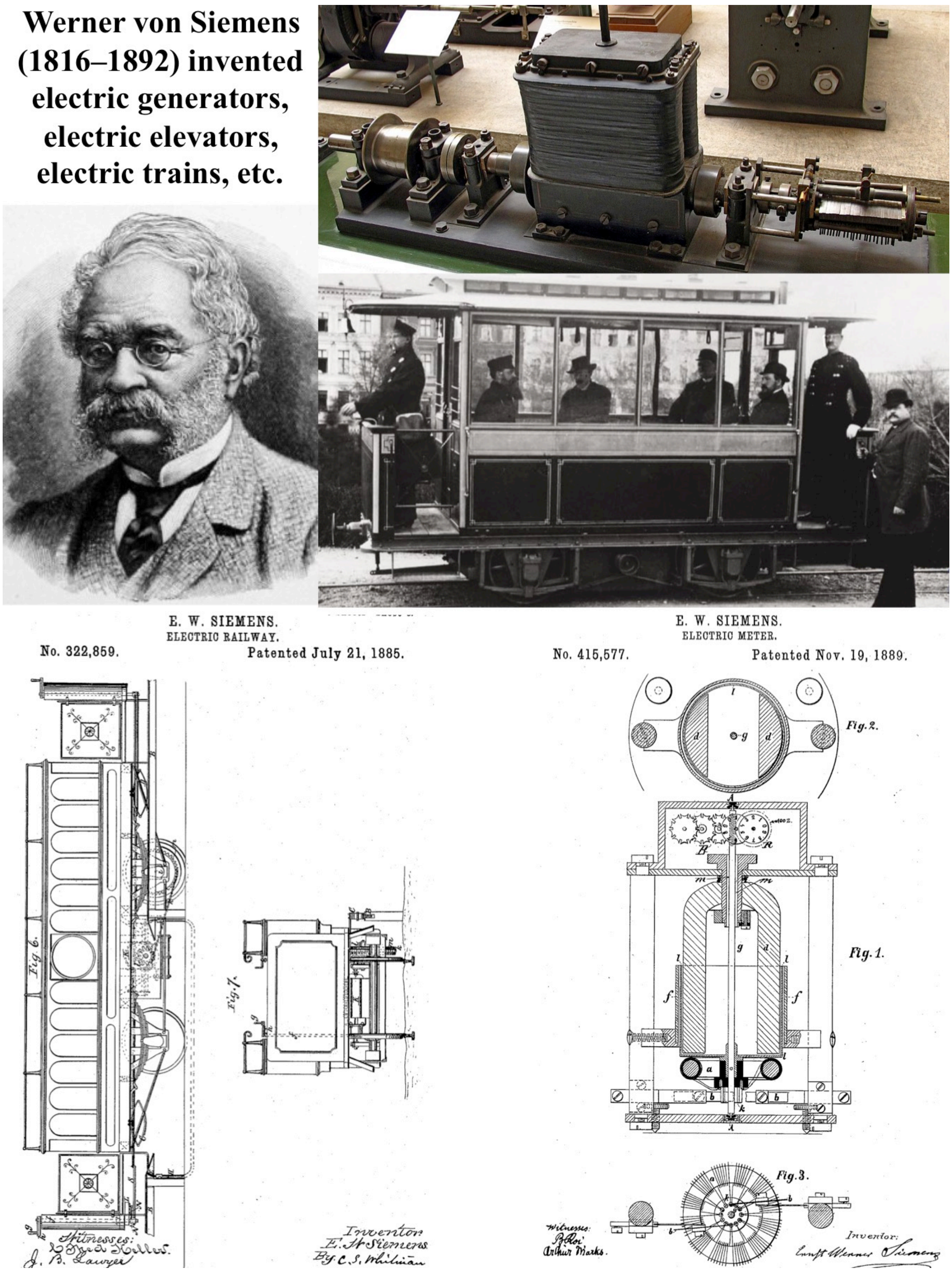


Figure 6.4: Werner von Siemens invented electric generators, electric elevators, electric trains, etc.

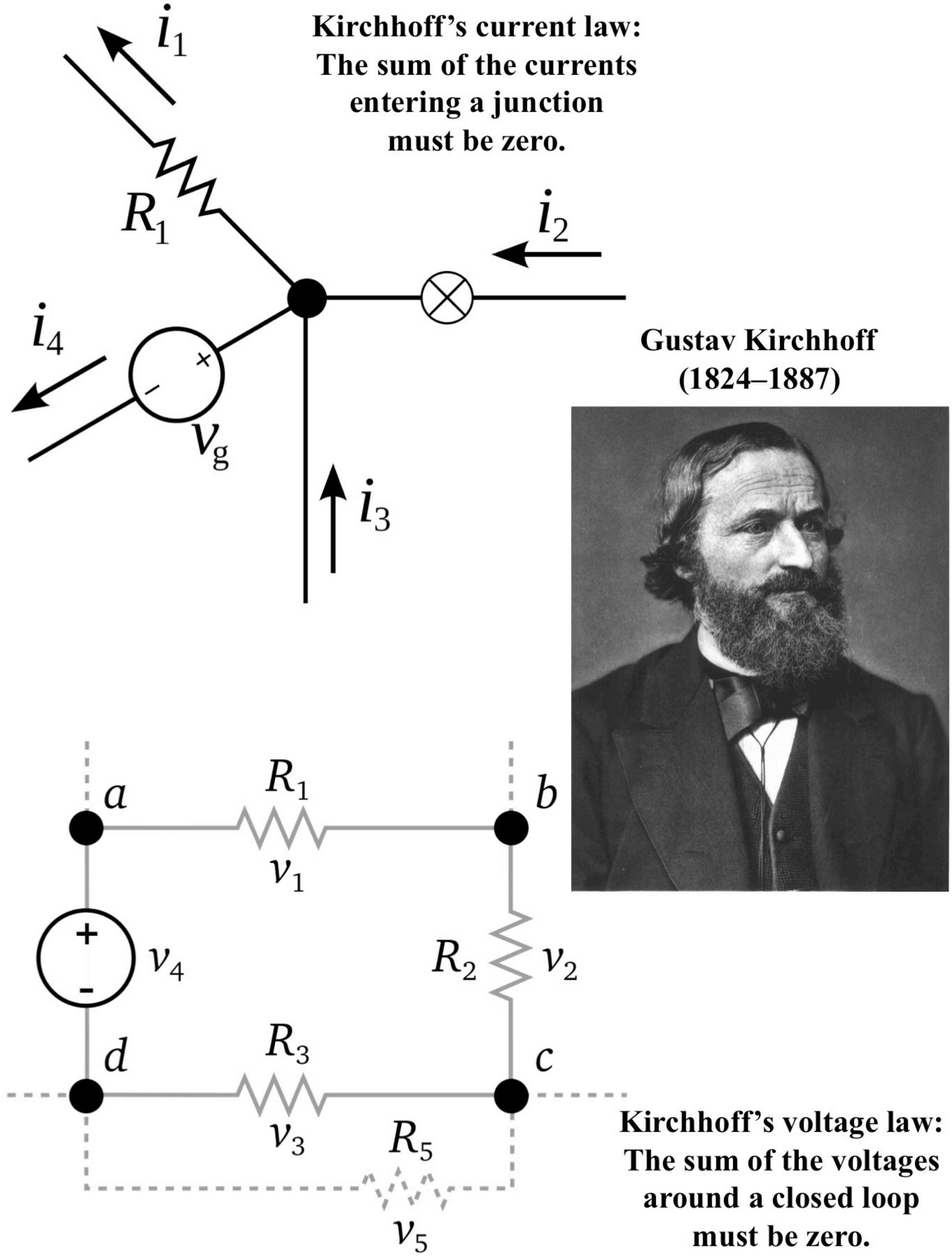
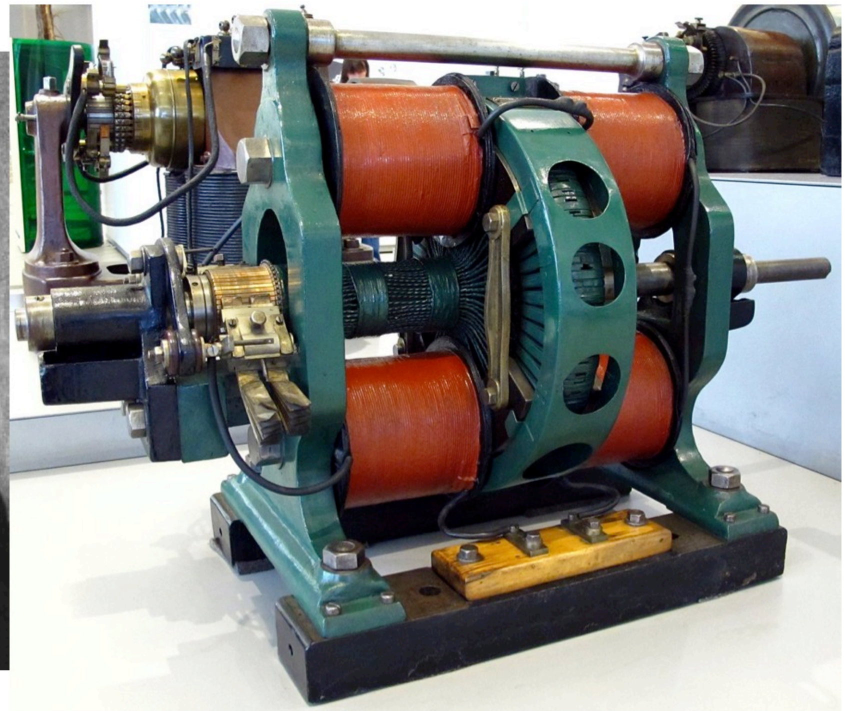


Figure 6.5: Gustav Kirchhoff discovered laws for currents and for voltages that are still widely used in analyzing electric circuits.

Johann Sigmund Schuckert (1846–1895)
improved electric generators and motors, and also
created some of the first lighting systems for streets and buildings



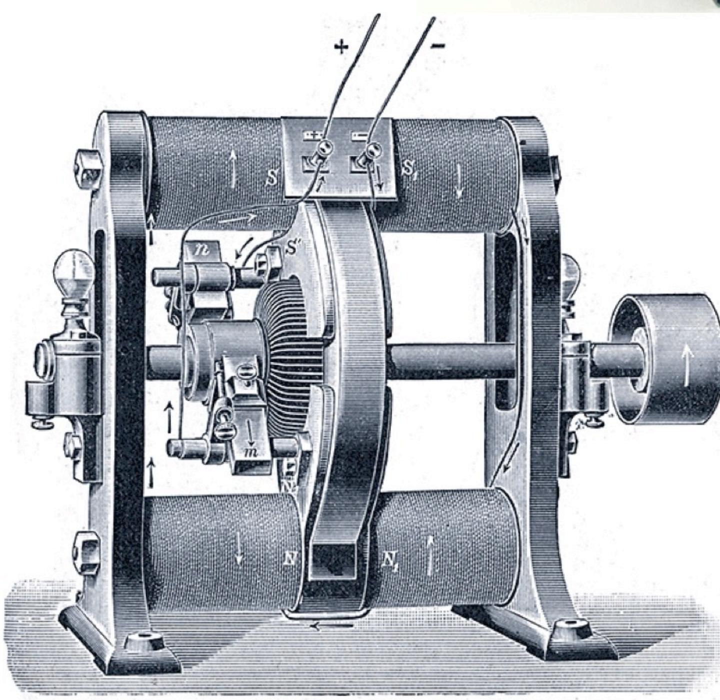


Fig. 368
Schuckertsche Flachringmaschine. Ansicht

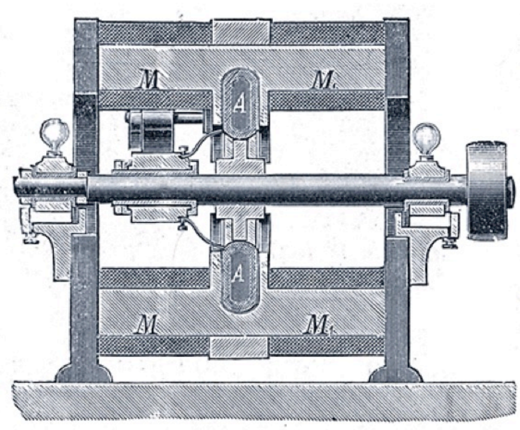
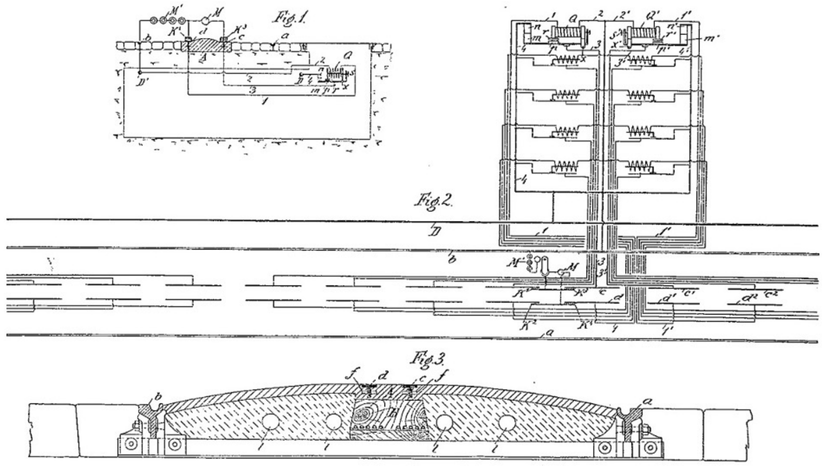
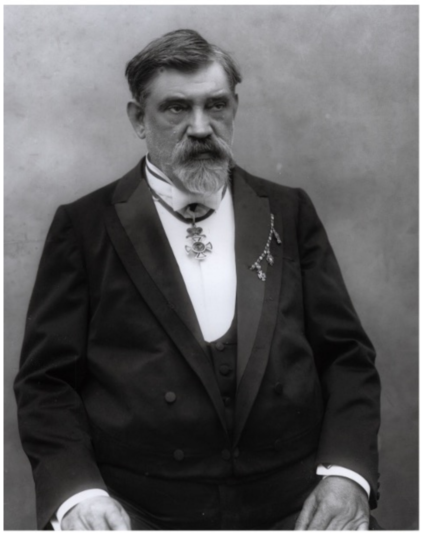


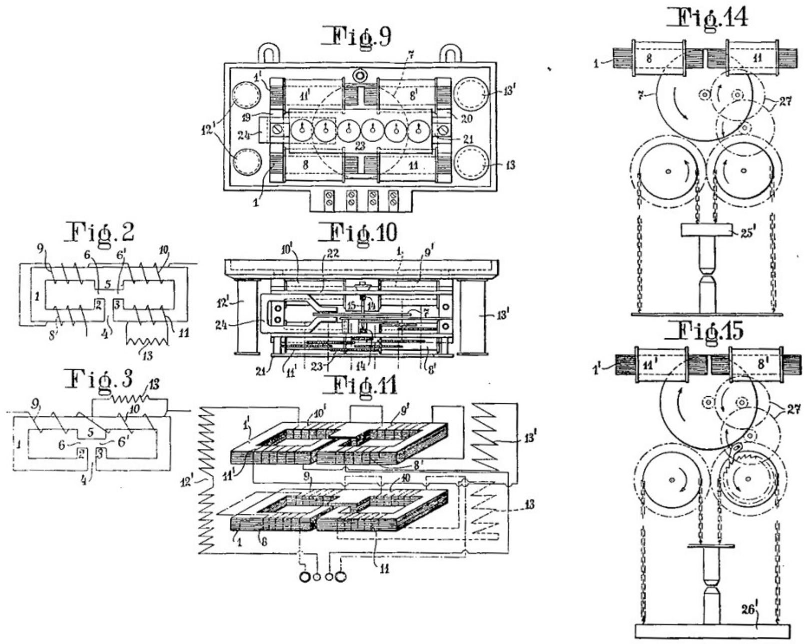
Fig. 369
Schuckertsche Flachringmaschine. Durchschnitt

Figure 6.6: Johann Sigmund Schuckert improved electric generators and motors, and also created some of the first lighting systems for streets and buildings.

František Křižík (1847–1941) created electric generators, electric motors, electric trains, electric cars, improved arc lamps, etc.







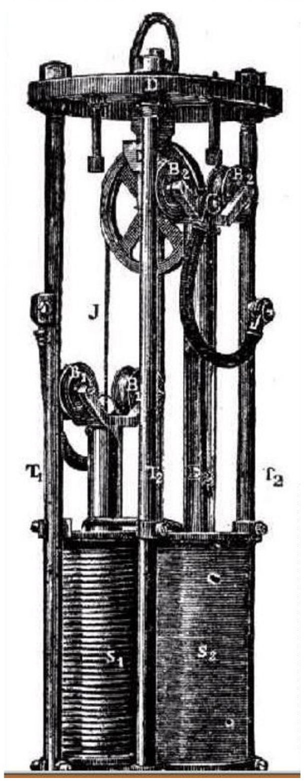
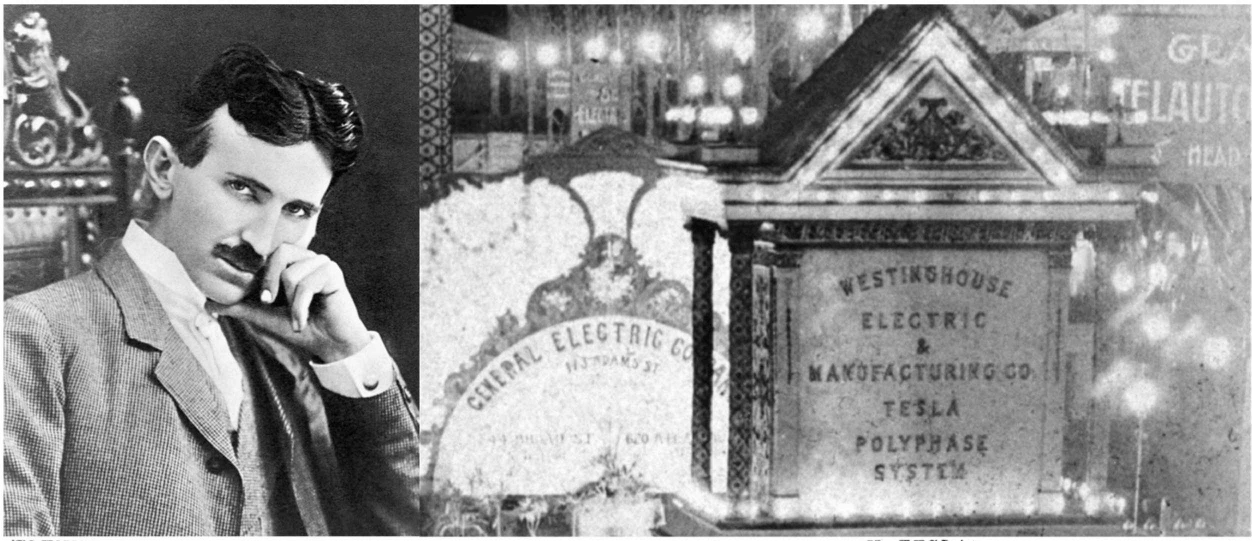


Figure 6.7: František Křižík created electric generators, electric motors, electric trains, electric cars, improved arc lamps, etc.

Nikola Tesla (1856–1943) invented a complete AC electric power generation, distribution, and usage system for Westinghouse in U.S.



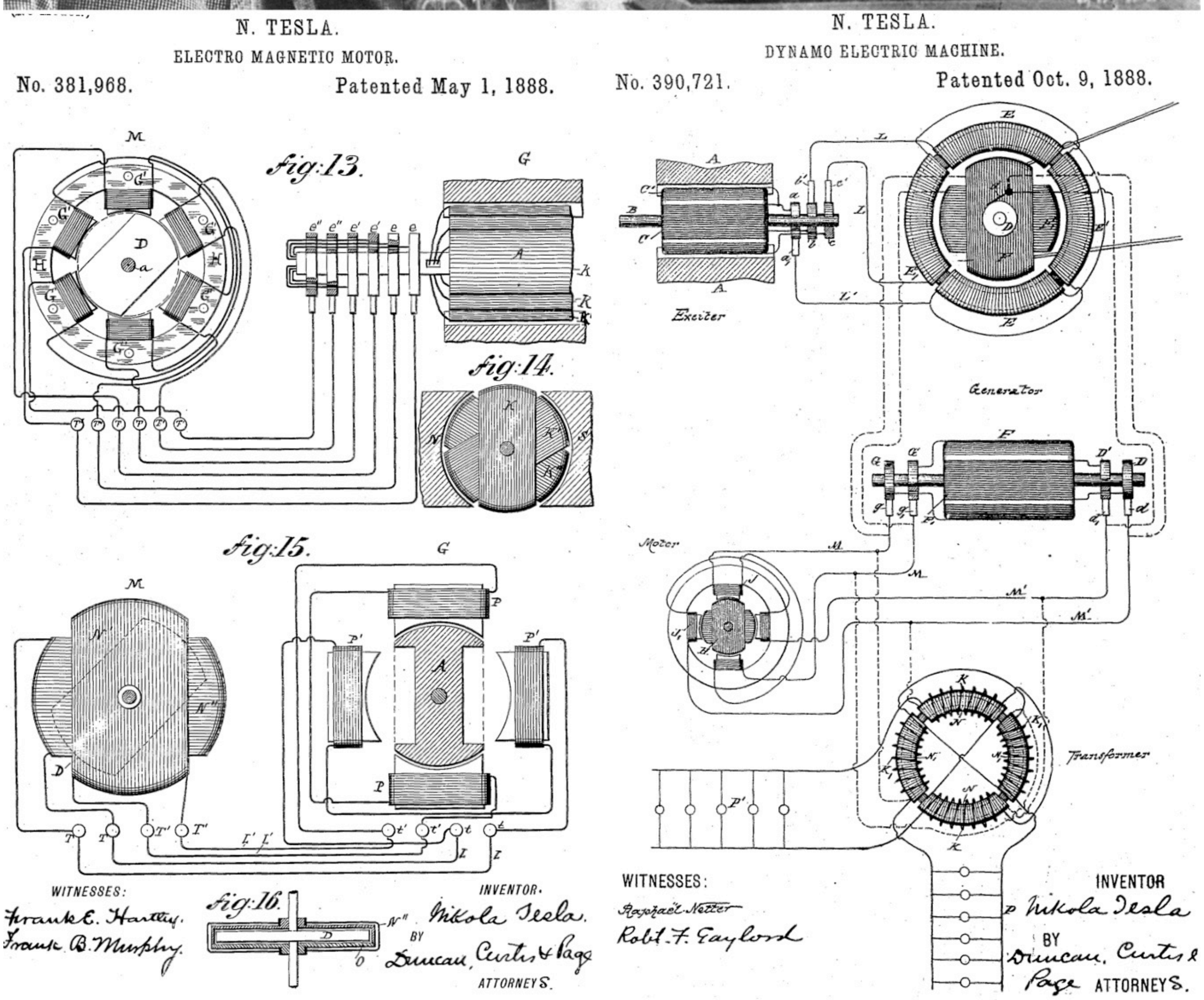


Figure 6.8: Nikola Tesla invented a complete AC electric power generation, distribution, and usage system for the Westinghouse company in the United States.

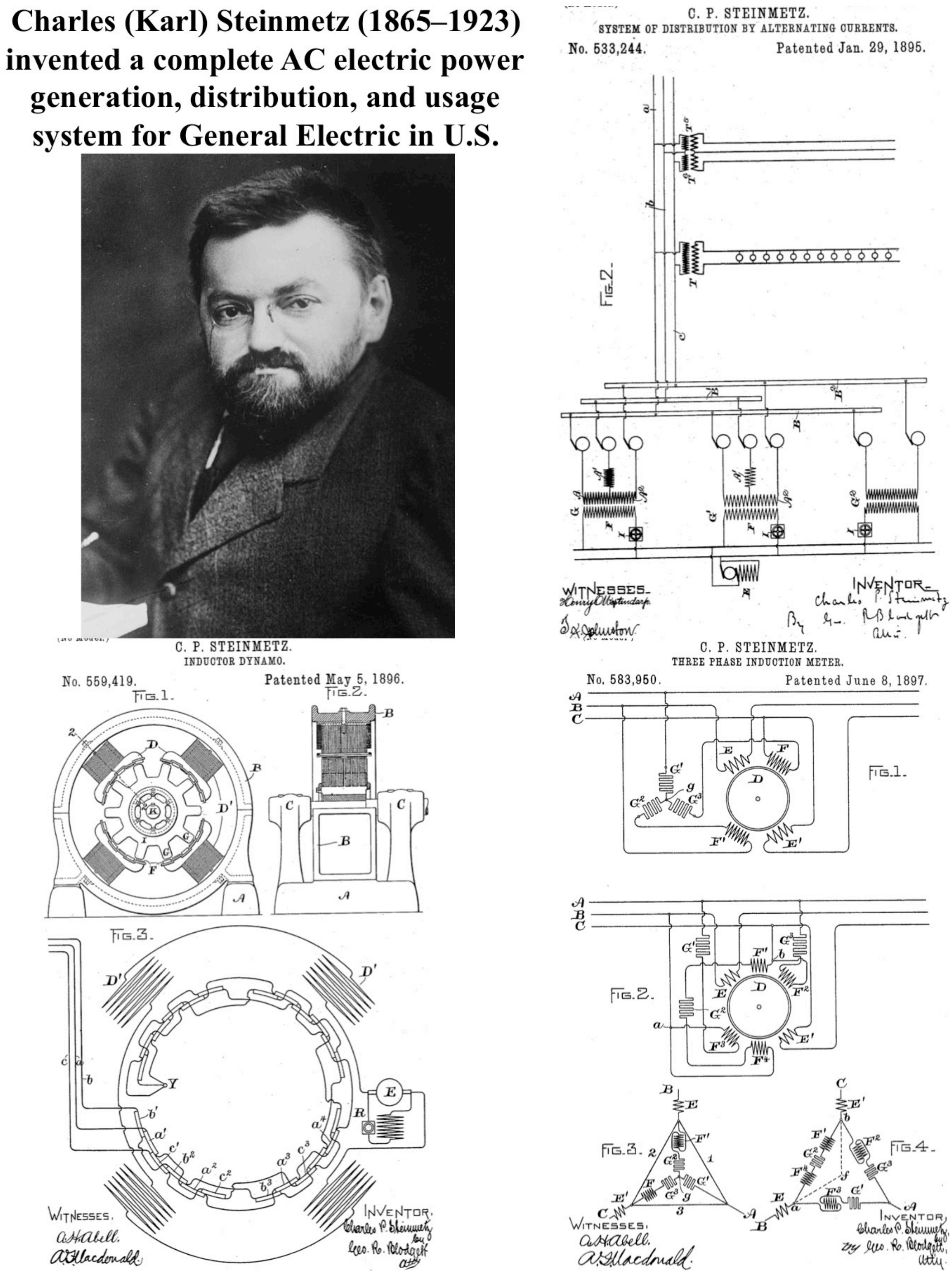


Figure 6.9: Charles (Karl) Steinmetz invented a complete AC electric power generation, distribution, and usage system for the rival General Electric company in the United States.

Wilhelm Emil Fein (1842–1898) **Carl Fein (18??–19??)**

Electric hand drill (1895)

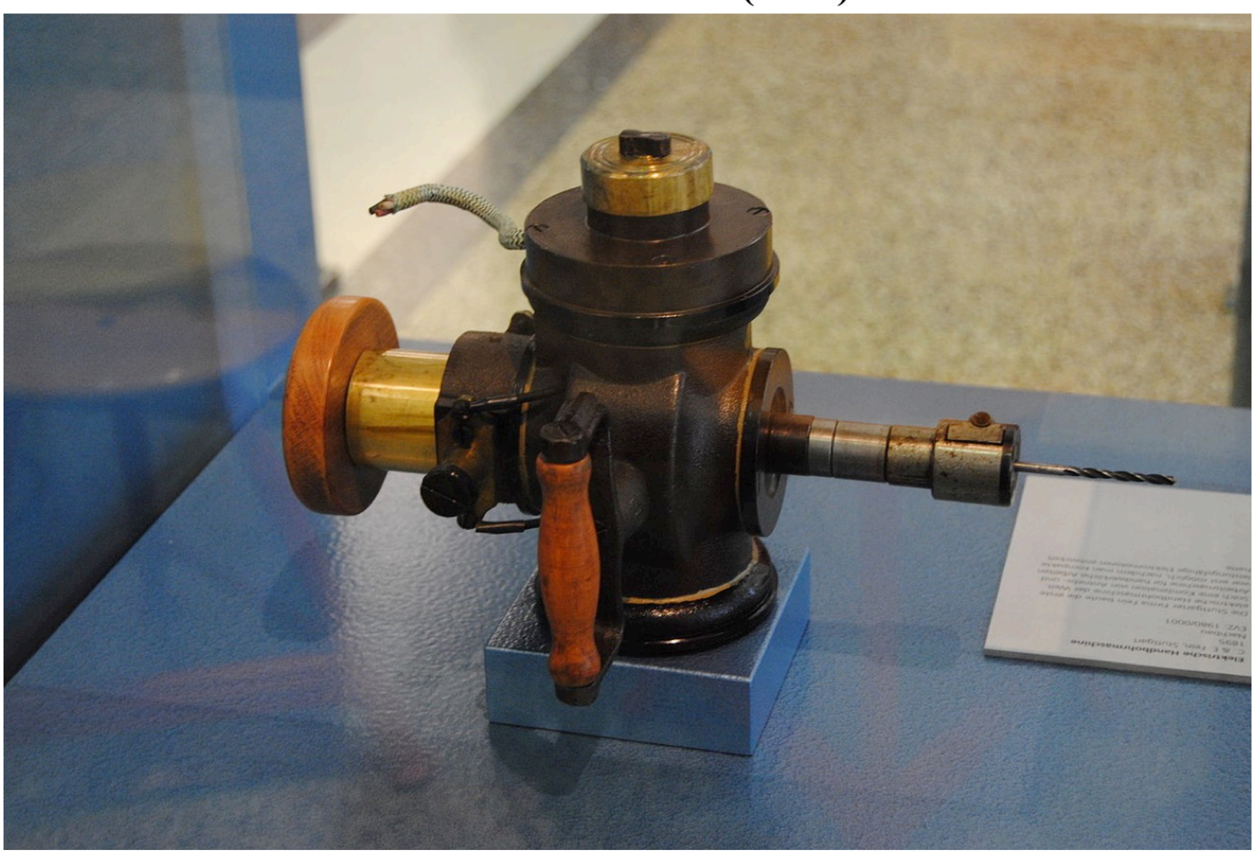


Figure 6.10: Brothers Wilhelm Emil Fein and Carl Fein invented the electric hand drill in 1895.

6.2 Lighting Technology

Creators from the German-speaking world pioneered all major categories of lighting science and technology. They developed spectroscopy to study visible light, and also discovered infrared and ultraviolet light (Section 6.2.1). They were directly responsible for inventing and developing all major types of artificial lighting—incandescent light bulbs (Section 6.2.2), fluorescent light tubes and their variations (Section 6.2.3), and light emitting diodes or LEDs (Section 6.2.4).

6.2.1 Tools for Analyzing the Visible Spectrum, Infrared, and Ultraviolet Light

Spectroscopy, the quantitative separation and measurement of different colors or wavelengths in light, was developed and demonstrated by Joseph von Fraunhofer (Bavarian, 1787–1826), Robert Bunsen (German, 1811–1899), and Gustav Kirchhoff (German, 1824–1887). See Figs. 3.4 and 6.11.

Using spectroscopy to search for energy beyond the colors of visible light, Friedrich Wilhelm (William) Herschel (Hanover, 1738–1822) discovered infrared light in 1800 [Herschel 1800]. See p. 1143. He also discovered the planet Uranus and made several other important astronomical discoveries (p. 809). For more information on infrared technologies, see Section 6.6.

Using spectroscopy in a very similar fashion to search beyond visible light, Johann Ritter (Prussian/Bavarian, 1776–1810) discovered ultraviolet light in 1801 (Fig. 6.11).

6.2.2 Incandescent Light Bulbs

There is significant evidence that Heinrich Göbel (German, 1818–1893) invented the first fully functional incandescent light bulb in 1854, 25 years before the much more famous light bulbs from Thomas Edison's laboratory.[3] See Fig. 6.12. Modern historians and archivists should examine Göbel's work more closely to clarify exactly what he did.

Even the light bulbs that Thomas Edison's laboratory produced in 1879 were heavily dependent upon German-speaking creators whom Edison employed. Those creators included:[4]

- Leonhard Sigmund Bergmann (German, 1851–1927, shown in Fig. 6.13) studied engineering in Thuringia. He was recruited by Edison in 1875, and he played an important role in the development of Edison's versions of the phonograph, telephone, and incandescent light bulb. After that, he worked relatively independently of Edison to produce a variety of electrical and mechanical devices in the United States. Around 1890, Bergmann returned to Germany, where he built up an industrial empire producing everything from electrical systems to steam turbines to automobiles.

[3] https://data.tmw.at/object/281276; https://www.zobodat.at/pdf/VeroeffFerd_83_0165-0184.pdf; Paturi 1998, pp. 338–339. For a contrary opinion see Rohde 2007.

[4] Conot 1979; Josephson 1959; http://www.lamptech.co.uk; https://ethw.org/John_Kruesi

- Ludwig Karl Böhm (German, 1859–after 1907, Fig. 6.14) was a student and assistant of Heinrich Geissler, a German inventor of electric lighting (p. 967), during the period 1871–1878. During the crucial period 1879–1880, he worked in Edison's laboratory, where he drew upon his previous experience to create the vacuum pumps, glass envelopes, electrical assemblies, and other key details for the first incandescent lamps that were produced and patented there. He appears to have become quickly disillusioned with Edison and spent the rest of his life working for other companies or for himself. During his life, Böhm produced an astonishing variety of inventions, including multiple types of electric lights, improved vacuum pumps, refrigerated railroad cars, paper-making machines, acetylene gas generators, carbide furnaces, automated money-handling machines, etc.

- Johann Heinrich "John" Krüsi (Swiss, 1843–1899, Fig. 6.15) was a skilled machinist and machine maker who was educated and worked in Europe, then was recruited by Edison in 1872. He became the head machinist in Edison's lab, where he either invented or directly helped to invent the Edison phonograph. After that, he worked on the development of incandescent light bulbs, as well as other associated electrical and mechanical components and inventions.

Thomas Edison and his companies also made use of the innovations of a number of other creators from the German-speaking world, including Robert Bosch (p. 1359), Johann Sigmund Schuckert (p. 961), Charles Steinmetz (p. 964), and Nikola Tesla (p. 963). The accumulated mythology surrounding Edison should be carefully reexamined by modern historians to assign proper credit for the innovations to the appropriate people.[5]

Whereas the first incandescent light bulbs used short-lived, soot-forming carbon filaments, German-speaking creators developed greatly improved incandescent bulbs that used longer-lived, cleaner, and more efficient metal filaments:

- Walther Nernst (German, 1864–1941, Fig. 6.16) invented zirconium filaments in 1897.

- Carl Auer von Welsbach (Austrian, 1858–1929, Fig. 6.16) invented osmium filaments in 1898. (He also invented the gaslight mantle in 1885 and the flint metal lighter in 1903, and he founded Auergesellschaft, Treibacher Industrie, and Osram.)

- Werner von Bolton (German, 1868–1912) and Otto Feuerlein (Swiss, 1863–1930) invented tantalum filaments in 1902. See Fig. 6.17.

- Alexander Just (German, 1874–1937) and Franjo Hanaman (Austro-Hungarian/Croatian, 1878–1941) invented tungsten filaments in 1904, and they have been widely used ever since (Fig. 6.17).

6.2.3 Gas Discharge and Fluorescent Light Tubes

Heinrich Geissler (German, 1814–1879), Julius Plücker (German states, 1801–1868), and Johann Hittorf (German, 1824–1914) developed and tested early high-voltage gas discharge tubes that were

[5] There also appear to have been other inventors in the English-speaking world, such as William Sawyer (U.S., 1850–1883) and Joseph Swan (English, 1828–1914), whose accomplishments have been unfairly slighted by all of the hagiography focused on Edison.

ultimately diversified into vacuum tubes, X-ray tubes, cathode ray tubes, neon lighting tubes, and fluorescent lighting tubes. See Fig. 6.18.

As shown in Fig. 6.19, Leo Arons (German, 1860–1919) modified high-voltage gas discharge tubes to create the mercury vapor lamp in 1892.

Edmund Germer (German, 1901–1987), Friedrich Meyer (German?, 18??–19??), and Hans Spanner (German?, 18??–19??) further modified high-voltage gas discharge tubes to invent modern fluorescent lighting tubes in 1926. Specifically, they coated mercury vapor lamp tubes with fluorescent chemical pigments to absorb the ultraviolet light emitted by the mercury and reemit that energy as a range of visible light. See Fig. 6.20.

Nikolaus Riehl (German, 1901–1990, p. 1637), one of the leading scientists of Auergesellschaft, also made important contributions to chemical pigments for fluorescent lighting and to the optical spectroscopy of solid materials.

Both before and after World War II, these lighting technologies were transferred from the German-speaking world to other countries. BIOS 395, *German Fluorescent Lamp Industry and Phosphor Chemical Manufacture*, pp. 3 and 5, provides an example of the transfer of information on improved fluorescent light tubes to the United Kingdom and United States:

> REPORT 2—DISCUSSION WITH DR. ABRAHAMOZIK, FORMERLY RESEARCH CHEMIST OF THE WELT-POST INSTITUTE, HEIDELBERG. 14.11.1945.
>
> [...] With Dr. Lappe, a physicist, he had been engaged on the preparation of metallic sulphides, selenides and tellurides by new methods employing furnacing at ultrahigh-pressures circa 1,000 atmospheres. The object was to obtain improved efficiency of transformation of long wave U.V. into visible radiation and secondly to produce fluorescent powders responsive to infra-red radiation of long wavelength corresponding with 400^{o}C radiators.
>
> Ultra-Violet Phosphors:
>
> A large range of possible substances had been investigated of which the most effective was found to be zinc sulphide containing 5% zinc selenide activated with 0.0001% Cu, up to 1% Cu. This material was stated to be some 30% to 50% more efficient than a simple zinc sulphide produced by the same method.
>
> I.R. Phosphors:
>
> To produce powders responsive to long wavelength I.R. radiation—zinc, lead, mercury, cadmium sulphides, selenides and tellurides had been investigated. The zinc sulphide + 5% selenide was good and the telluride compound was probably better but less was known about the properties.
>
> These latter compounds were used in receiving circuits for detecting I.R. by employing the phosphor as the dielectric of a condenser fitted in a sensitive valve receiver. Reception

of I.R. radiation was indicated by circuit changes resulting from changes in the dielectric constant of the phosphor.

Gilles Holst (Dutch, 1886–1968) and Willem Uyterhoeven (Dutch, 18??–19??) invented sodium vapor lamps in 1932, as shown in Fig. 6.21. Holst was the research director at the Philips Eindhoven laboratory [VanDelft 2014], which was closely tied to the rest of the predominantly German-speaking research world from the late nineteenth century through World War II, including work on electronics, communications, and directed energy beams.[6] Holst was also involved in research toward the development of transistors (pp. 1065–1066 and 2698–2701).

6.2.4 Light Emitting Diodes (LEDs)

Bernhard Gudden (German, 1892–1945), Robert Pohl (German, 1884–1976), Zoltan Bay (Hungarian, 1900–1992), György Szigeti (Hungarian, 1905–1978), and Kurt Lehovec (Bohemian/Austrian/Czech, 1918–2012) developed light emitting diodes (LEDs). See pp. 1115–1117 and Section B.4.

[6] See for example: CIOS III-1; CIOS VI-26, 27; CIOS X-13; CIOS XI-10; CIOS XII-22.

Joseph von Fraunhofer (standing, 1787–1826), Robert Bunsen (1811–1899), & Gustav Kirchhoff (1824–1887) developed spectroscopy

Johann Ritter (1776–1810) discovered ultraviolet light

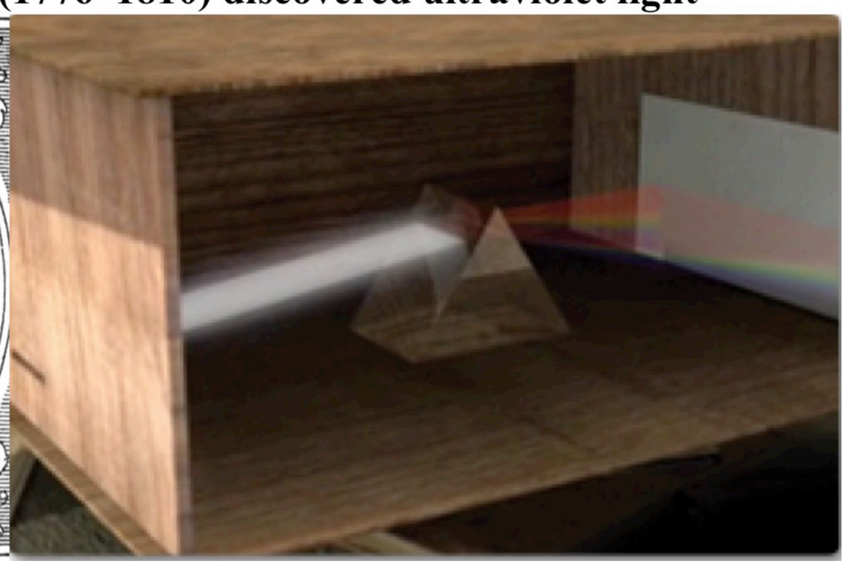


Figure 6.11: Joseph von Fraunhofer (standing), Robert Bunsen (Fig. 3.4), and Gustav Kirchhoff (Fig. 3.4) developed spectroscopy. Johann Ritter discovered ultraviolet light.

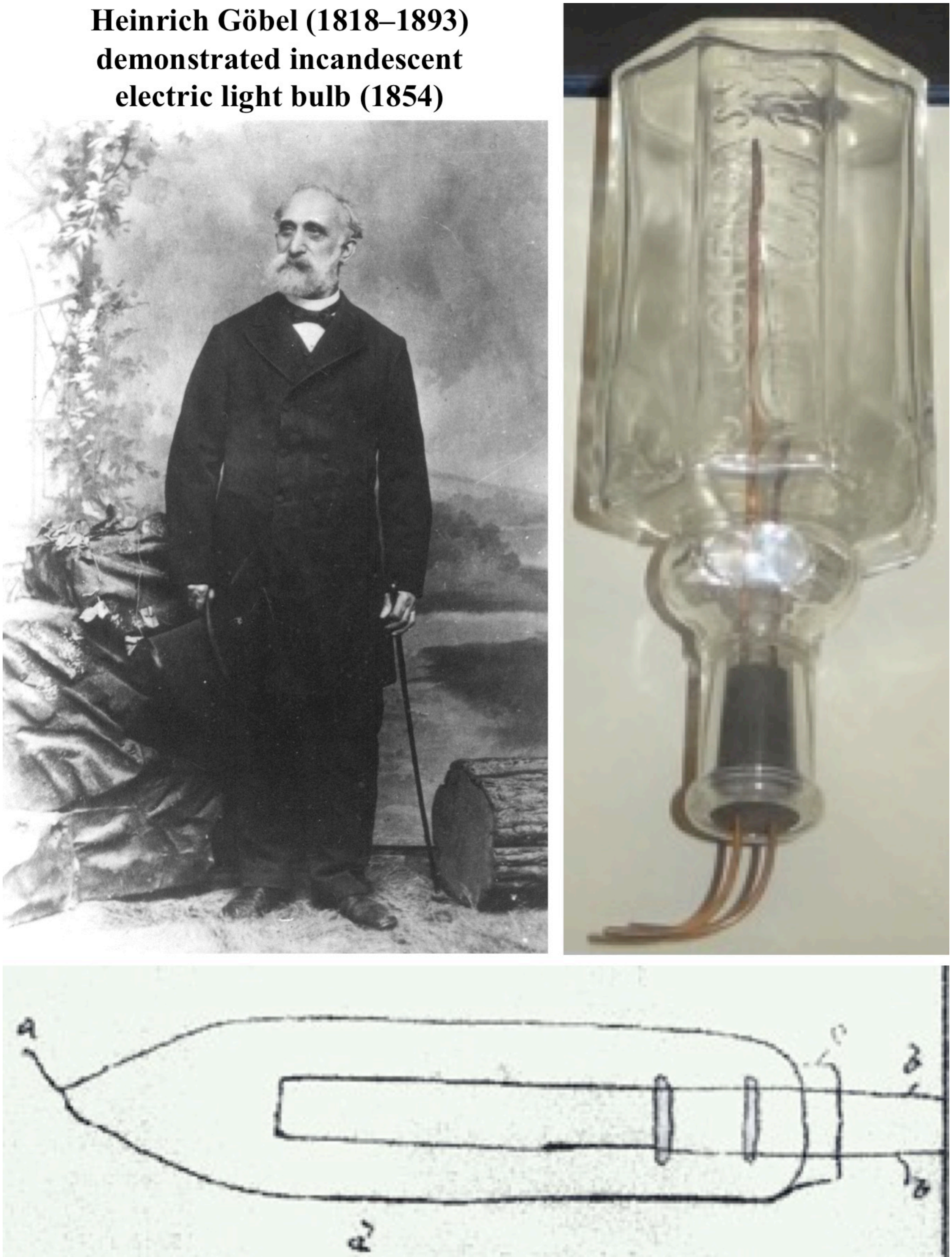


Figure 6.12: There is significant evidence that Heinrich Göbel (1818–1893) invented the first functional incandescent light bulb in 1854, 25 years before the much more famous light bulbs from Thomas Edison's laboratory.

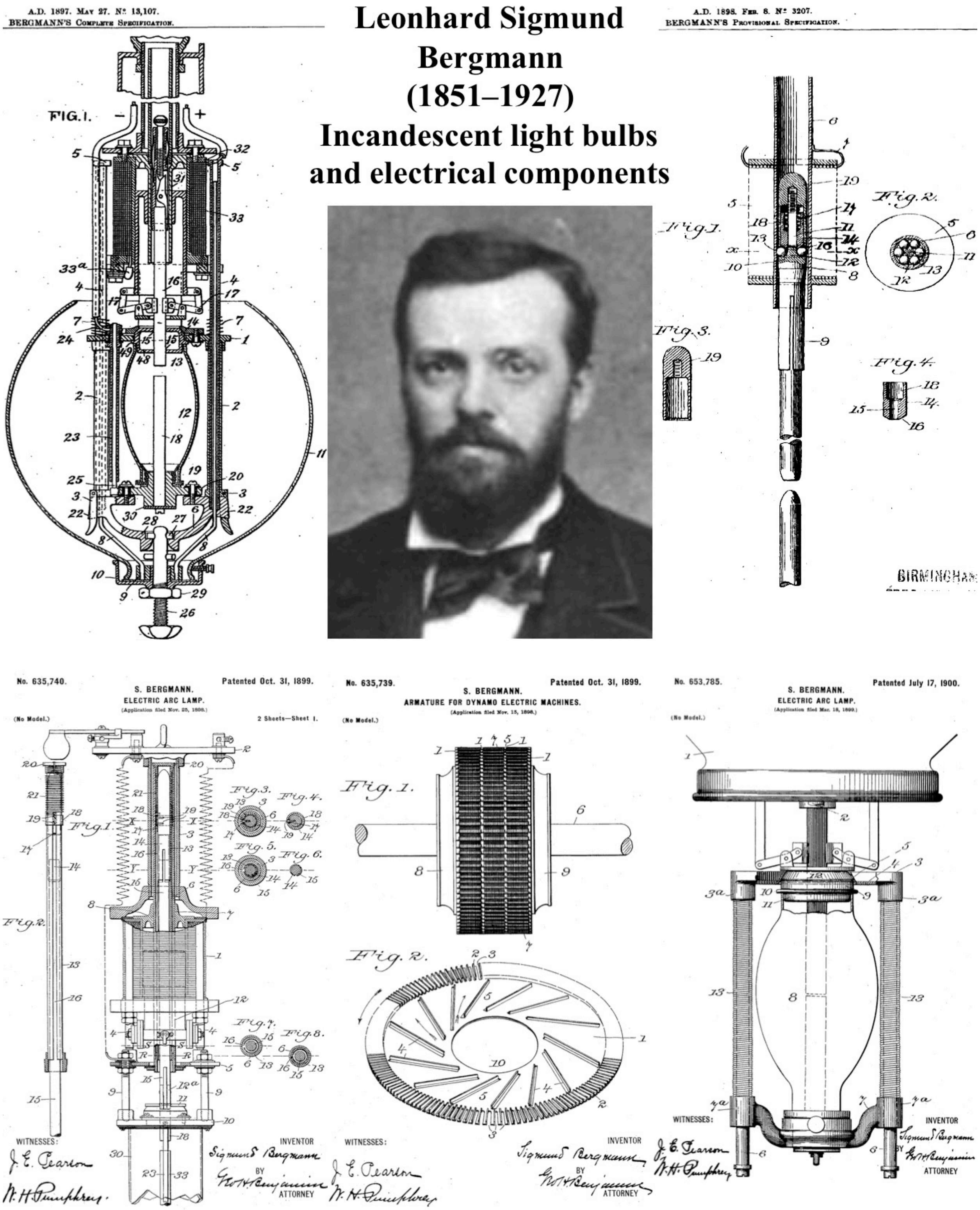


Figure 6.13: Leonhard Sigmund Bergmann helped to develop the first incandescent light bulbs that Thomas Edison's laboratory made, then went into business for himself creating various electrical and mechanical devices.

Ludwig Karl Böhm (1859–after 1907)
Incandescent light bulbs and many other inventions

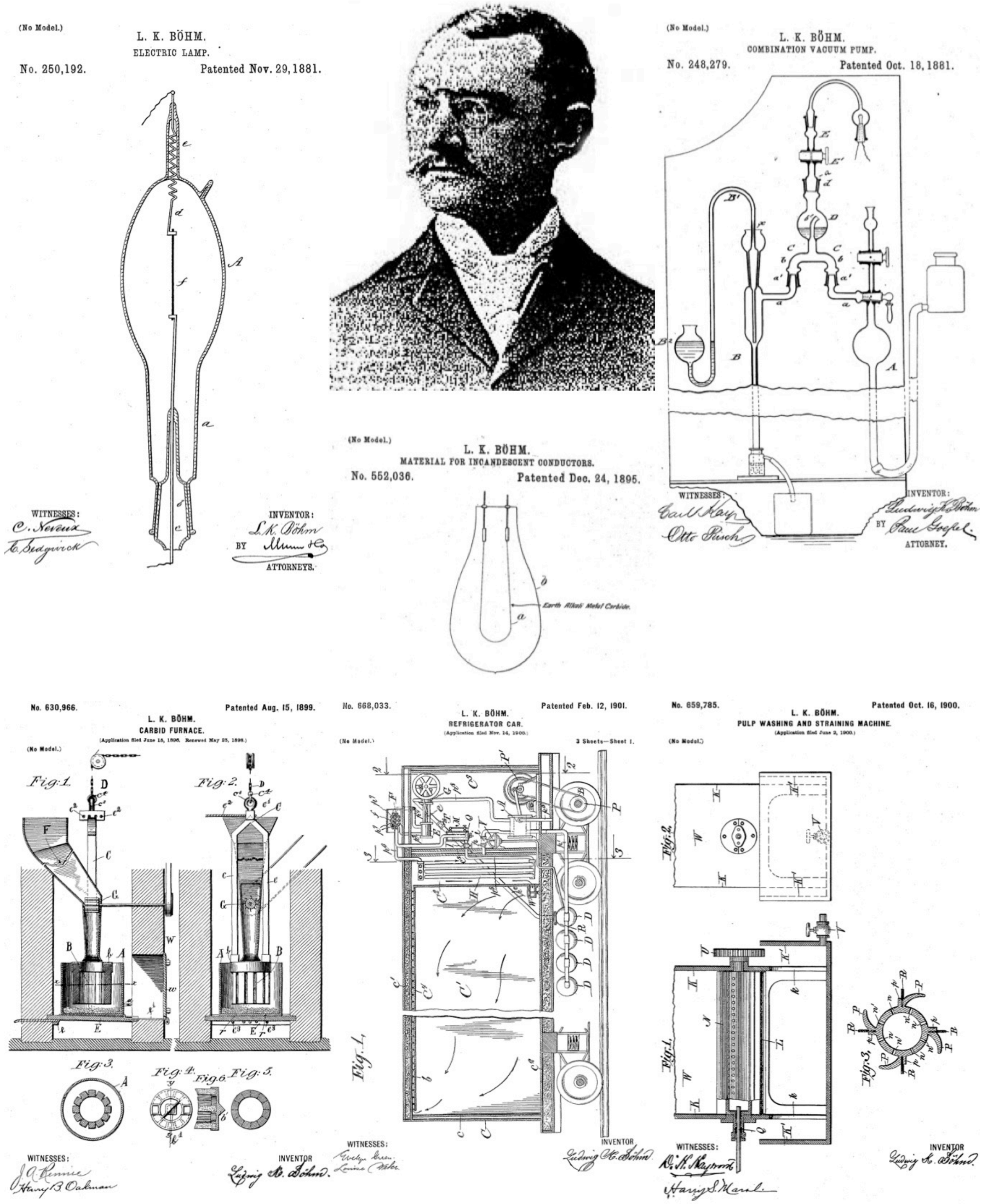


Figure 6.14: Ludwig Karl Böhm helped to develop the first incandescent light bulbs that Thomas Edison's laboratory made, then worked for other companies. In addition to light bulbs, he created a wide variety of other inventions.

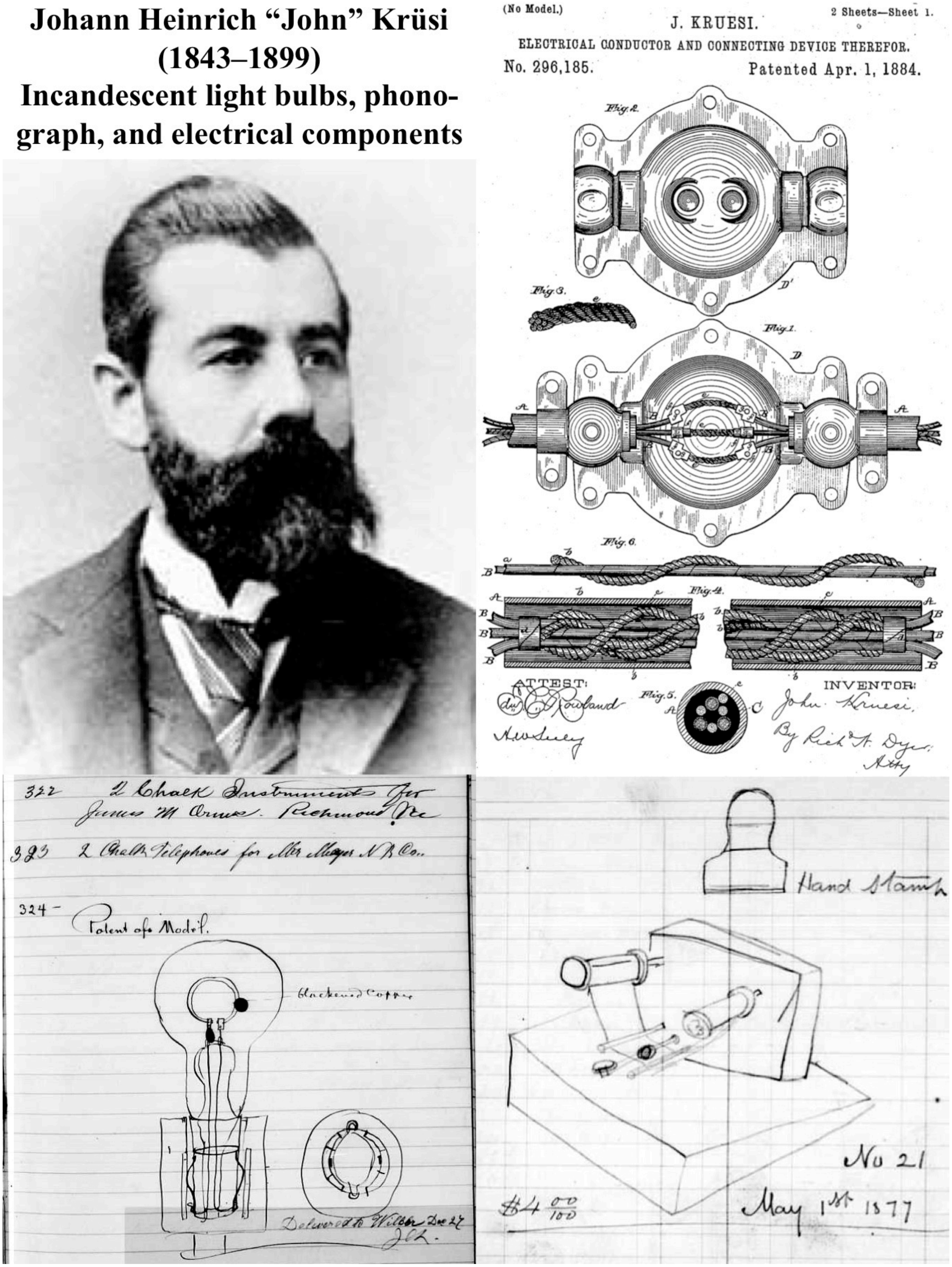


Figure 6.15: Johann Heinrich “John” Krüsi helped to develop the first incandescent light bulbs that Thomas Edison’s laboratory made. He also invented or helped to invent the Edison phonograph and other innovations that came out of that laboratory.

Figure 6.16: Walther Nernst invented zirconium metal filaments for incandescent light bulbs in 1897. Carl Auer von Welsbach invented osmium filaments in 1898.

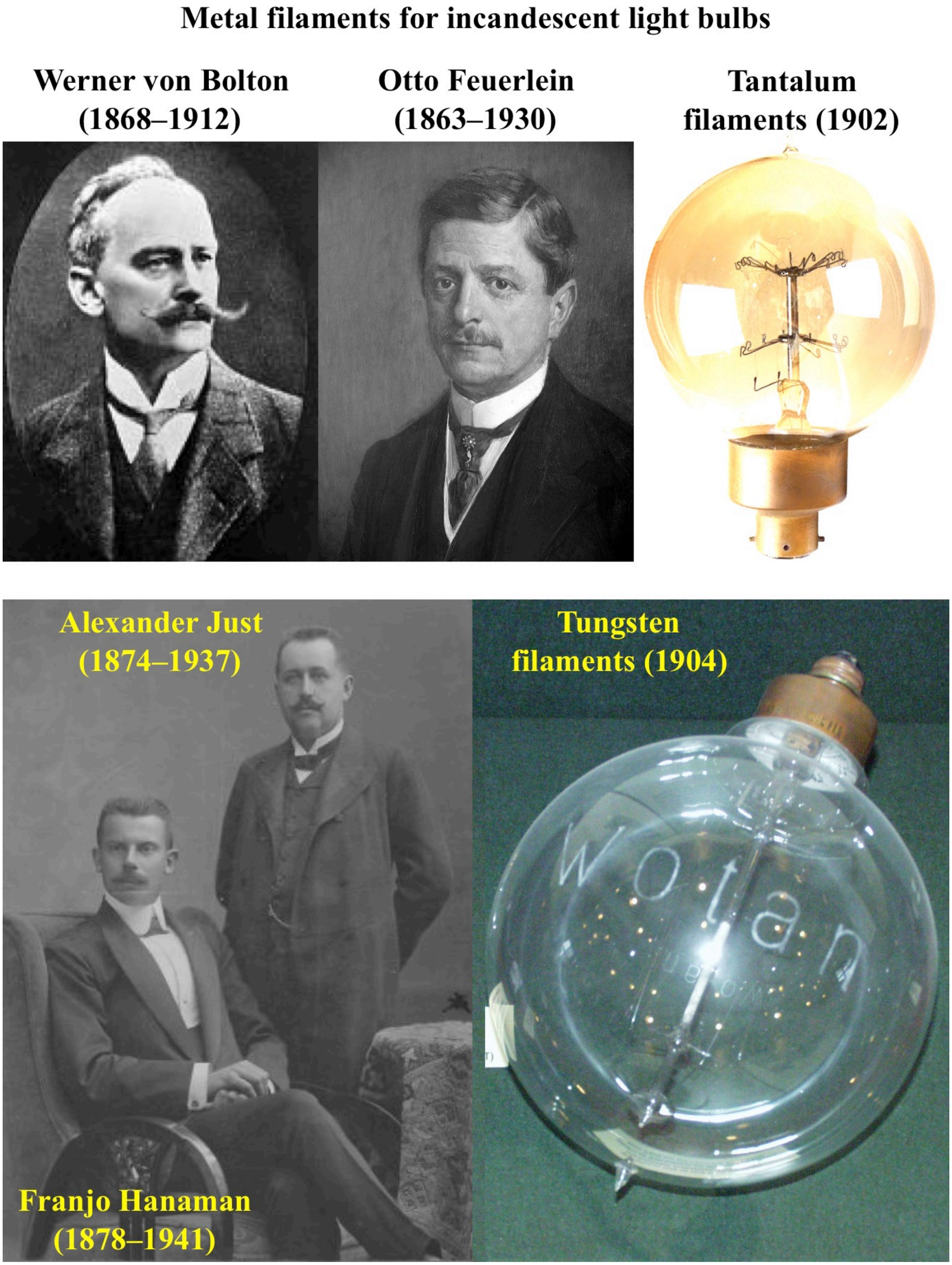


Figure 6.17: Werner von Bolton and Otto Feuerlein invented tantalum metal filaments for incandescent light bulbs in 1902. Alexander Just and Franjo Hanaman invented tungsten filaments in 1904.

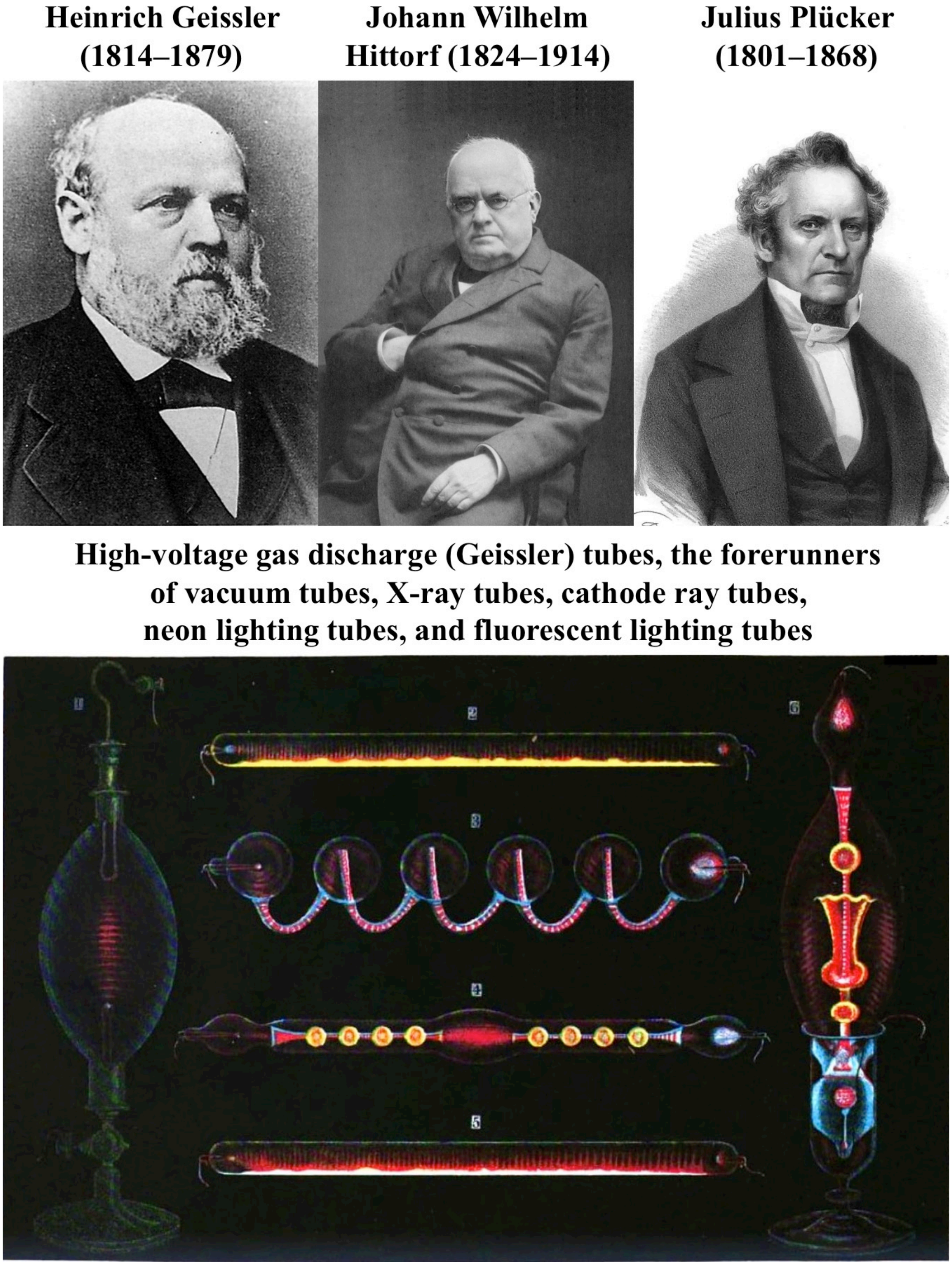


Figure 6.18: Heinrich Geissler, Johann Wilhelm Hittorf, and Julius Plücker created high-voltage gas discharge (Geissler) tubes, the forerunners of vacuum tubes, X-ray tubes, cathode ray tubes, neon lighting tubes, and fluorescent lighting tubes.

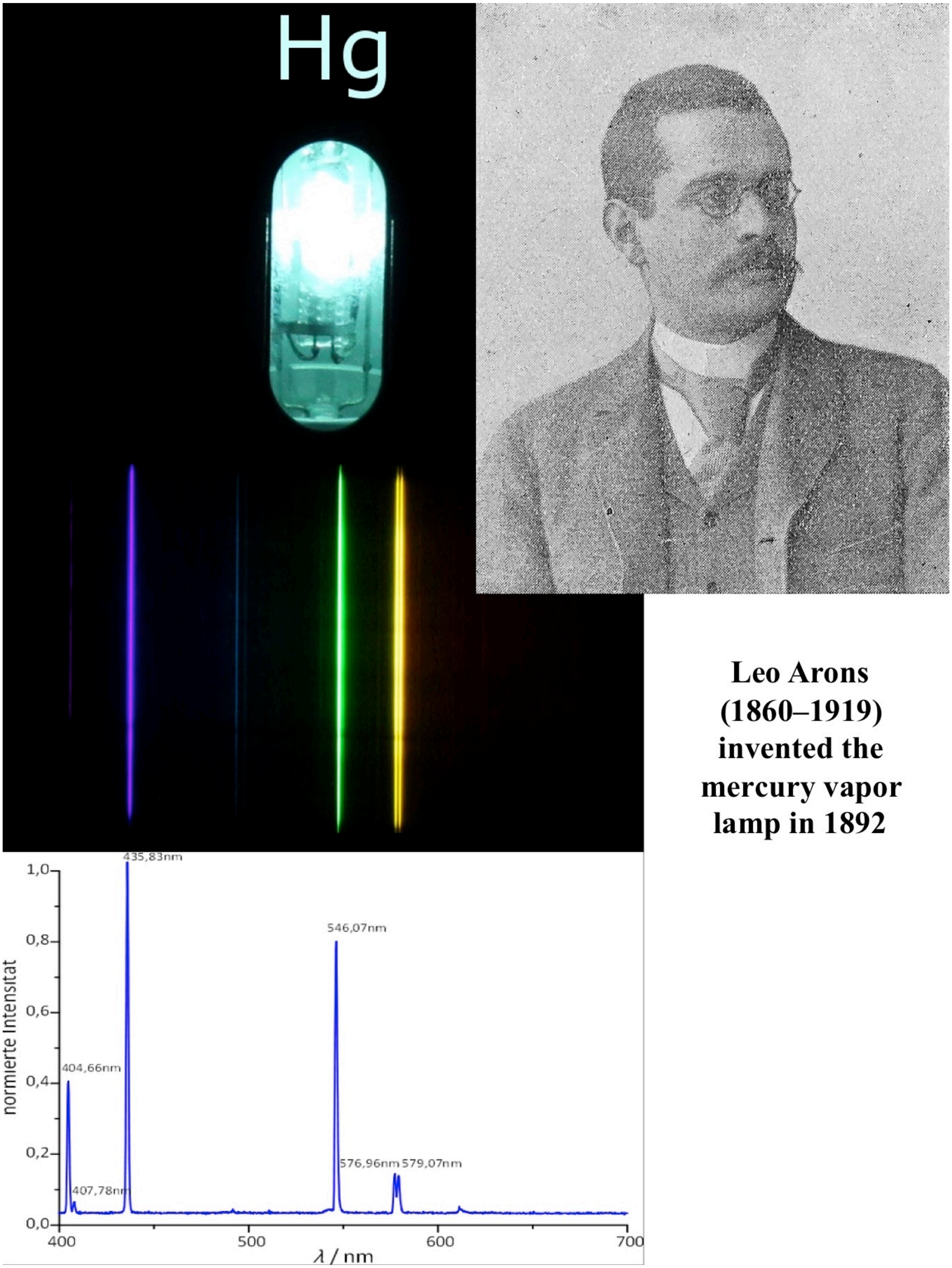


Figure 6.19: Leo Arons invented the mercury vapor lamp in 1892.

Edmund Germer (1901–1987) **Friedrich Meyer (18??–19??)** **Hans Spanner (18??–19??)**

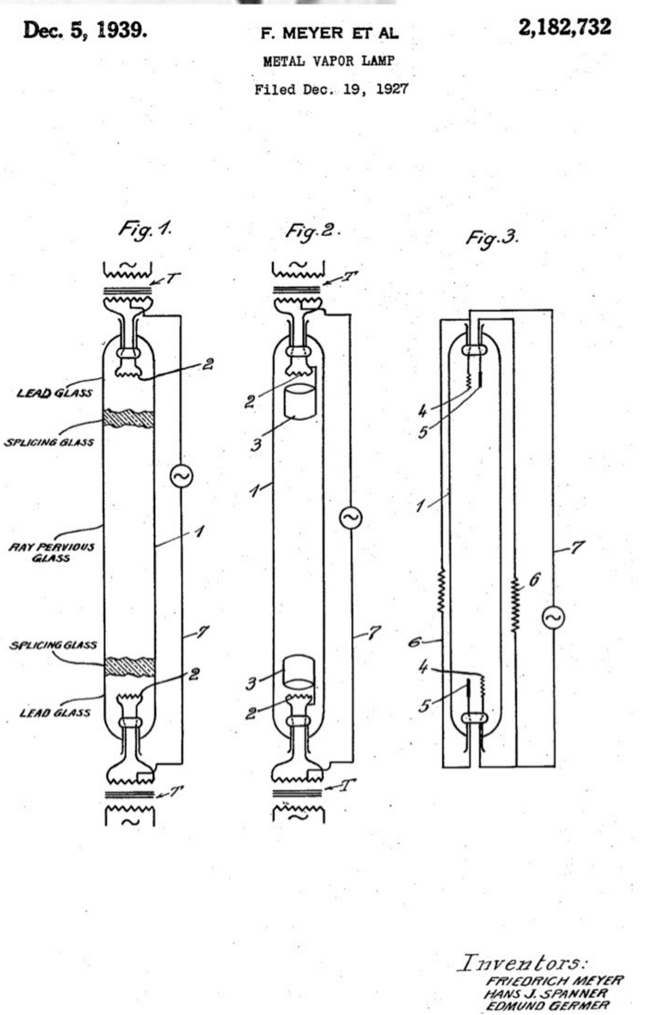
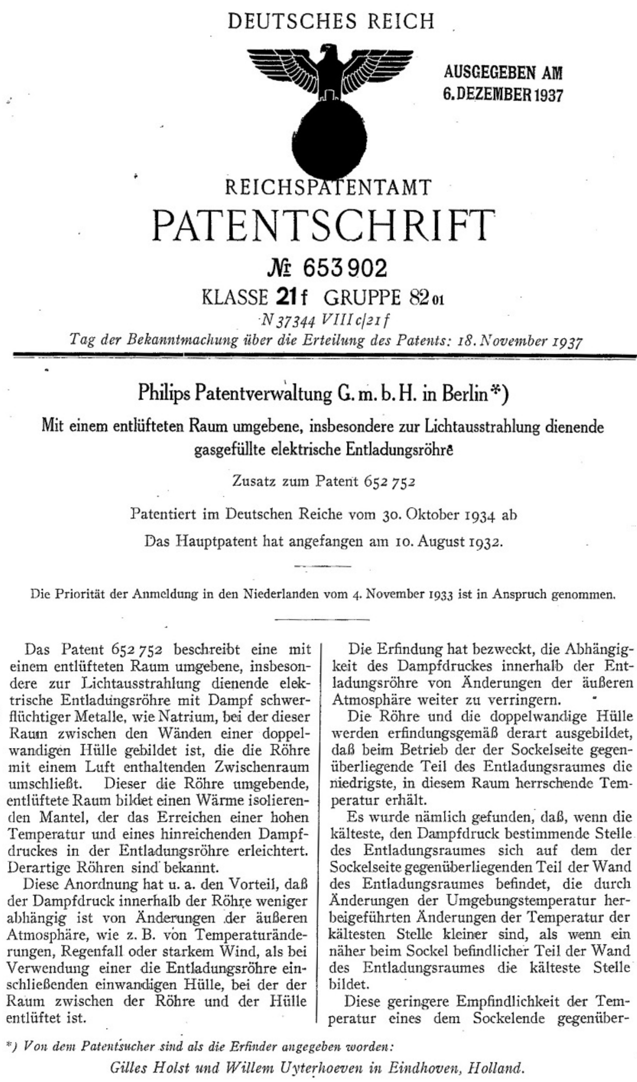


Figure 6.20: Edmund Germer, Friedrich Meyer, and Hans Spanner modified mercury vapor tubes to invent modern fluorescent lighting tubes in 1926.

Sodium vapor lamp (1932)

Gilles Holst (1886–1968)

Willem Uyterhoeven (18??–19??)



DEUTSCHES REICH

AUSGEGEBEN AM 6. DEZEMBER 1937

REICHSPATENTAMT

PATENTSCHRIFT

№ 653 902

KLASSE 21f GRUPPE 82 01

N 37344 VIII c/21 f

Tag der Bekanntmachung über die Erteilung des Patents: 18. November 1937

Philips Patentverwaltung G. m. b. H. in Berlin*)

Mit einem entlüfteten Raum umgebene, insbesondere zur Lichtausstrahlung dienende gasgefüllte elektrische Entladungsröhre

Zusatz zum Patent 652 752

Patentiert im Deutschen Reiche vom 30. Oktober 1934 ab

Das Hauptpatent hat angefangen am 10. August 1932.

Die Priorität der Anmeldung in den Niederlanden vom 4. November 1933 ist in Anspruch genommen.

Das Patent 652 752 beschreibt eine mit einem entlüfteten Raum umgebene, insbesondere zur Lichtausstrahlung dienende elektrische Entladungsröhre mit Dampf schwerflüchtiger Metalle, wie Natrium, bei der dieser Raum zwischen den Wänden einer doppelwandigen Hülle gebildet ist, die die Röhre mit einem Luft enthaltenden Zwischenraum umschließt. Dieser die Röhre umgebende, entlüftete Raum bildet einen Wärme isolierenden Mantel, der das Erreichen einer hohen Temperatur und eines hinreichenden Dampfdruckes in der Entladungsröhre erleichtert. Derartige Röhren sind bekannt.

Diese Anordnung hat u. a. den Vorteil, daß der Dampfdruck innerhalb der Röhre weniger abhängig ist von Änderungen der äußeren Atmosphäre, wie z. B. von Temperaturänderungen, Regenfall oder starkem Wind, als bei Verwendung einer die Entladungsröhre einschließenden einwandigen Hülle, bei der der Raum zwischen der Röhre und der Hülle entlüftet ist.

Die Erfindung hat bezweckt, die Abhängigkeit des Dampfdruckes innerhalb der Entladungsröhre von Änderungen der äußeren Atmosphäre weiter zu verringern.

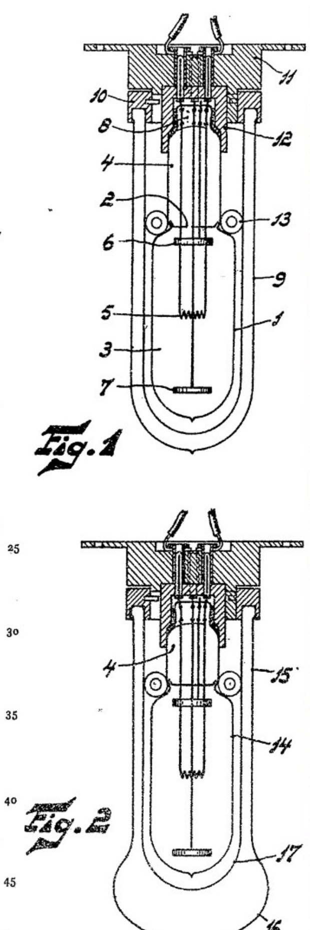
Die Röhre und die doppelwandige Hülle werden erfindungsgemäß derart ausgebildet, daß beim Betrieb der der Sockelseite gegenüberliegende Teil des Entladungsraumes die niedrigste, in diesem Raum herrschende Temperatur erhält.

Es wurde nämlich gefunden, daß, wenn die kälteste, den Dampfdruck bestimmende Stelle des Entladungsraumes sich auf dem der Sockelseite gegenüberliegenden Teil der Wand des Entladungsraumes befindet, die durch Änderungen der Umgebungstemperatur herbeigeführten Änderungen der Temperatur der kältesten Stelle kleiner sind, als wenn ein näher beim Sockel befindlicher Teil der Wand des Entladungsraumes die kälteste Stelle bildet.

Diese geringere Empfindlichkeit der Temperatur eines dem Sockelende gegenüber-

**) Von dem Patentsucher sind als die Erfinder angegeben worden:*

Gilles Holst und Willem Uyterhoeven in Eindhoven, Holland.



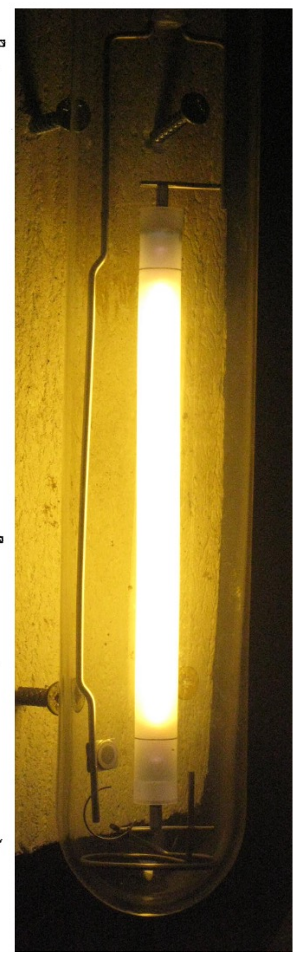


Figure 6.21: Gilles Holst and Willem Uyterhoeven invented sodium vapor lamps in 1932.

6.3 Communications and Recording Technologies

German-speaking creators invented and demonstrated communications and recording technologies that revolutionized the world:

6.3.1. Telegraphs

6.3.2. Telephones

6.3.3. Radio

6.3.4. Mobile telephone systems

6.3.5. Optical communications systems

6.3.6. Disc phonograph records and players

6.3.7. Magnetic tape recording

6.3.8. Motion picture cameras and projectors

6.3.9. Television

6.3.10. Video telephone system

6.3.11. Scanners, facsimile (fax) machines, and printers

6.3.12. Photocopiers

6.3.13. Optical discs and digital file formats

Unfortunately, the modern world often does not attribute these inventions to their actual creators.

6.3.1 Telegraphs

Carl Friedrich Gauss (German states, 1777–1855) and Wilhelm Weber (German, 1804–1891), shown in Fig. 6.22, worked out the laws of magnetism and electromagnetism. Using those, they invented and demonstrated the world's first electric (electromagnetic or electromechanical) telegraph in 1833, five years before Samuel Morse, whose work became much better known outside the German-speaking world [Dunnington 1955]. (See also pp. 746, 800, 836, and 866.)

In a 20 November 1833 letter from Carl Friedrich Gauss to Heinrich Olbers, Gauss described the design and successful operation of his telegraph [English translation by Guy Waldo Dunnington, in Dunnington 1955, p. 147]:

> I don't remember my having made any previous mention to you of an astonishing piece of mechanism that we have devised. It consists of a galvanic circuit conducted through wires stretched through the air over the houses up to the steeple of St. John's Church and down again, and connecting the observatory with the physics laboratory, which is under the direction of Weber. The entire length of wire may be computed at about eight thousand feet; both ends of the wire are connected with a multiplicator, the one at my end consisting of 170, that in Weber's laboratory of 50, coils of wire each wound around a one-pound magnet suspended according to a method which I have devised. By a simple contrivance—which I have named a commutator—I can reverse

> the current instantaneously. Carefully operating my voltaic pile, I can cause so violent a motion of the needle in the laboratory to take place that it strikes a bell, the sound of which is audible in the adjoining room. This serves merely as an amusement. Our aim is to display the movements with the utmost accuracy. We have already made use of this apparatus for telegraphic experiments, which have resulted successfully in the transmission of entire words and small phrases. This method of telegraphing has the advantage of being quite independent of either daytime or weather; the ones who receive it remain in their rooms, and if they desire it, with the shutters drawn. The employment of sufficiently stout wires, I feel convinced, would enable us to telegraph with but a single tap from Göttingen to Hanover, or from Hanover to Bremen.

Dunnington summarized further details about the history of the Gauss-Weber telegraph [Dunnington 1955, pp. 147–148, 150]:

> Gauss gave first public notice of the telegraph in the *Göttingische gelehrte Anzeigen*, issue of August 9, 1834. He gives detailed information about the "great galvanic circuit" between the physics laboratory and the observatory, to which the new magnetic observatory was connected, and emphasizes that this "unique setup" is due to Weber. The two had begun their electrical measurements on October 21, 1832. Gauss ordered magnetometers of varying size, from which he proceeded to larger magnets, and thus a number of galvanometers of varying size and construction came into being, although we do not know which ones were finally used in telegraphing. They were all to be used for this purpose, but the two scientists realized that the apparatus with the smallest magnets was best adapted for telegraphing on account of the magnets' small period of oscillation.
>
> It is reported that the first words sent on the telegraph were: *Michelmann kommt.* Michelmann was a servant who ran errands for Gauss and Weber. At first individual words were sent, and then complete sentences. The telegraph was operated once in the presence of the Duke of Cambridge, who seemed to take special interest in it.
>
> Weber's correspondence with the city council in April and May, 1833, gave exact information about the purpose and date of origin of the telegraph. At first Weber had used thin copper wire for the lines, which, however, did not stand up very well and had to be replaced by stronger wire. Even the latter did not resist weathering and was replaced by soft steel wire of one-millimeter strength. The lines existed until 1845, when they were destroyed by lightning on December 16. [...]
>
> The success of Gauss and Weber with their telegraph aroused great attention at that time, at least in Germany. Steps were under way to use it on the railroad. Gauss and Weber both wrote memoranda on the subject to the directorate of the Leipzig-Dresden railroad then under construction.

In 1846, Werner von Siemens (German, 1816–1892, Fig. 6.23) created more sophisticated telegraphs that could point to individual letters [Bähr 2016; von Siemens 1895]. Von Siemens also invented and sold a number of other important electrical components and systems (p. 953). Backed by a large industry and using more advanced designs, the von Siemens telegraphy systems overtook the demonstrations and proposals of Gauss and Weber. Werner von Siemens and Carl Wilhelm Siemens (German, 1823–1883), one of his younger brothers, designed and produced telegraph networks that were used in Europe and worldwide.

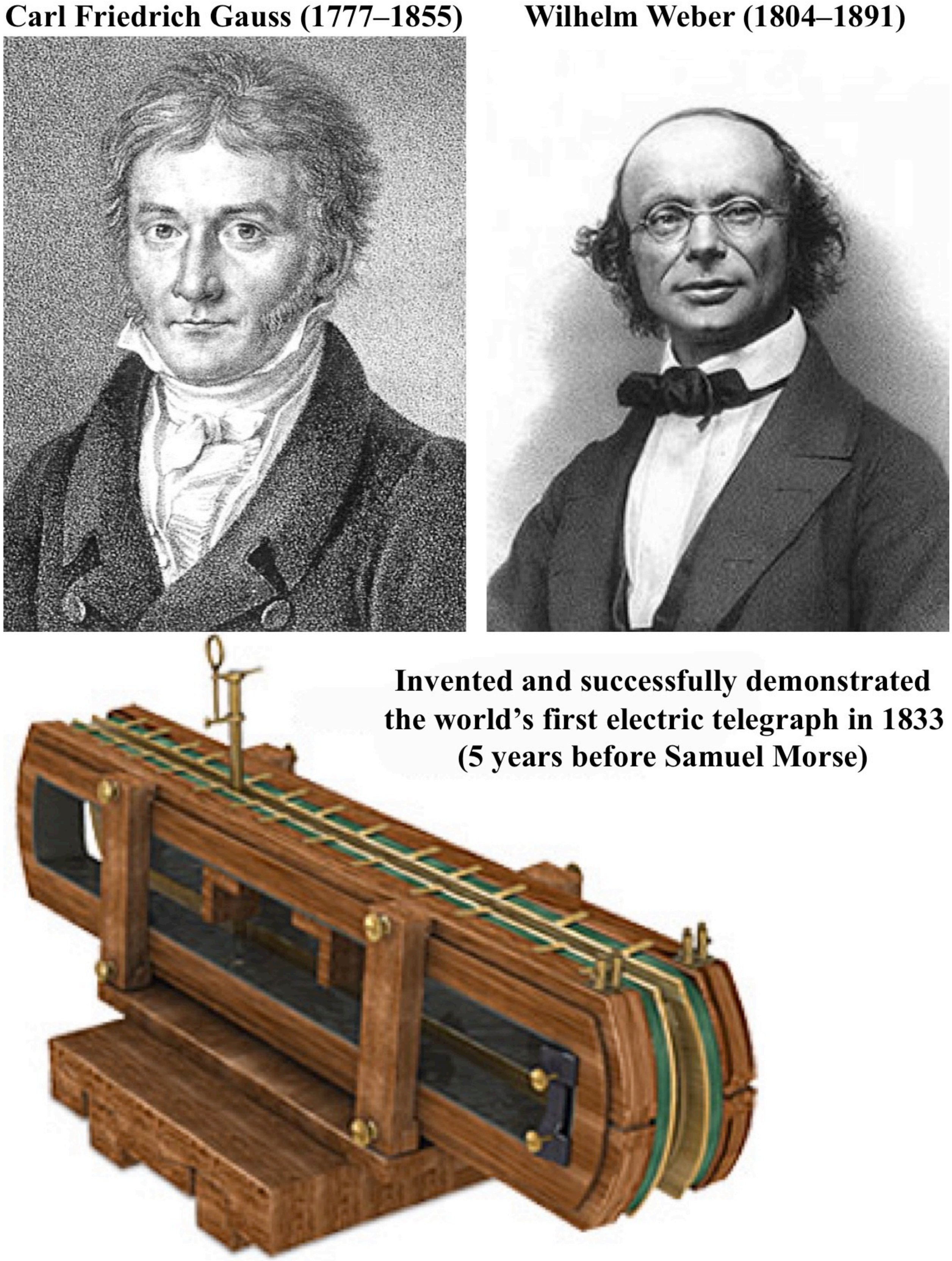


Figure 6.22: Carl Friedrich Gauss and Wilhelm Weber invented and successfully demonstrated the world's first electric telegraph in 1833 (five years before Samuel Morse).

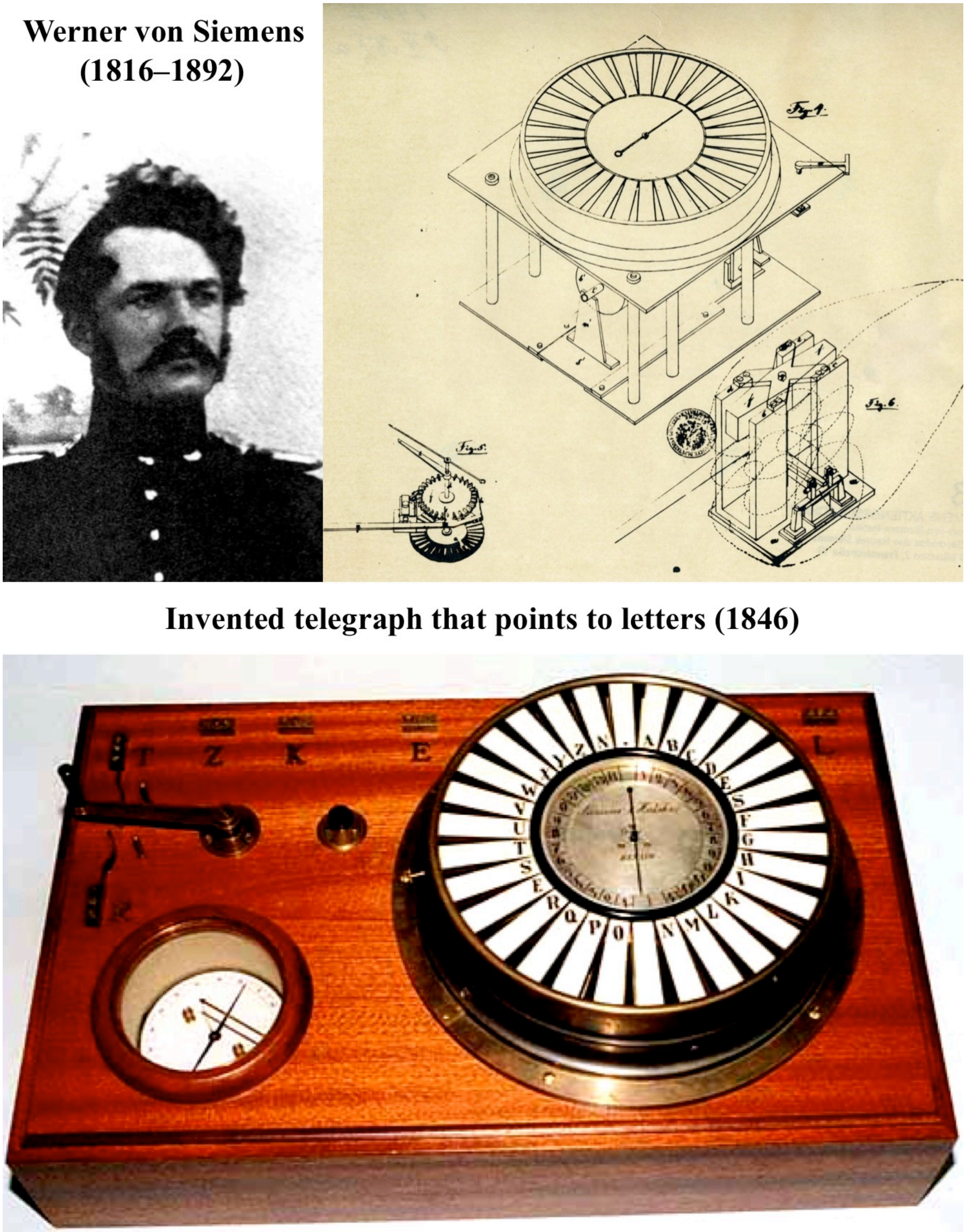


Figure 6.23: In 1846, Werner von Siemens created more sophisticated telegraphs that could point to individual letters.

6.3.2 Telephones

Johann Philipp Reis (German, 1834–1874) invented and successfully demonstrated the world's first microphone, speaker, and telephone in 1860 (Fig. 6.24). He then publicized and sought funding to improve his telephone. Reis demonstrated this working telephone system 16 years before Alexander Graham Bell's version in 1876, yet nowadays Reis is virtually unknown in the non-German-speaking world, and Bell is widely viewed as the inventor of the telephone. In 2003, BBC News confirmed that "Bell 'did not invent telephone'" [http://news.bbc.co.uk/2/hi/science/nature/3253174.stm]:

> Claims that a German scientist invented the telephone 15 years before Alexander Graham Bell are supported by evidence from newly surfaced archive papers.
>
> Successful tests on a German device manufactured in 1863 were covered up to maintain the Scot's reputation, the previously unseen files have revealed.
>
> They show the "Telephon", developed by German research scientist Philipp Reis, could transmit and receive speech.
>
> It is alleged UK businessman Sir Frank Gill was behind the cover-up.
>
> The evidence is contained in files from the archives of the Science Museum in London.
>
> The documents were rediscovered in October by the museum's curator of communications, John Liffen.
>
> Gill was chairman of Standard Telephones and Cables (STC), the company that conducted the tests on Reis's device.
>
> The company was at the time bidding for a contract from the American Telephone and Telegraph Company, which evolved from the Bell Company.
>
> Gill thought that if word got out of the test results, it would scupper STC's chances of winning the contract.
>
> Some researchers have argued for many years that Reis beat Bell to the invention of the telephone. The archived documents seem to support their claims.
>
> A memo, dated 18 March 1947, from Gerald Garratt, a predecessor of Mr Liffen's, show STC's reports on Reis's device were given to him under the strict condition that they would never be publicly referred to or published without permission.
>
> STC then became anxious to retrieve the documents. In a subsequent letter, Garratt wrote: "I am left with the thought that there is something so secret about [the documents] as to be a matter of first class historic interest.
>
> "You must know as well as I the old controversy: 'Did Bell invent the telephone?' and I have here an unpublished manuscript of over 400 pages which proves pretty conclusively that he didn't.
>
> "Does your anxiety to retrieve these reports rather suggest that you agree?"

Werner von Siemens (German, 1816–1892, Fig. 6.23) invented improved speakers.

Telephone

Johann Philipp Reis
(1834–1874)
invented and
successfully demonstrated
the world's first microphone
and telephone in 1860
(16 years before
Alexander Graham Bell)

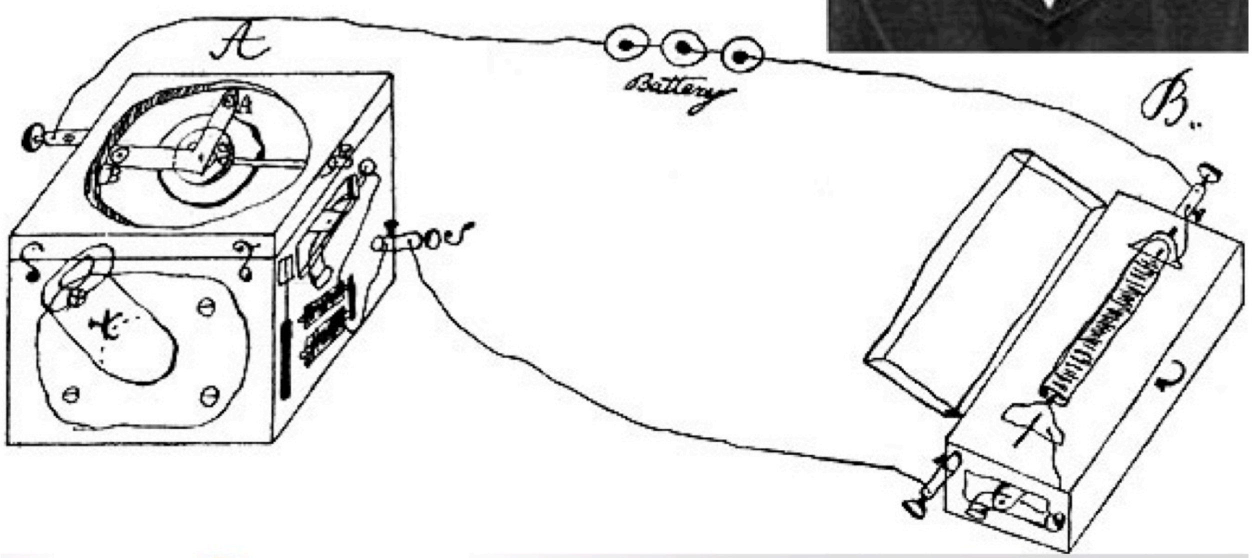


Figure 6.24: Johann Philipp Reis invented and successfully demonstrated the world's first microphone and telephone in 1860 (16 years before Alexander Graham Bell).

6.3.3 Radio

In 1888, Heinrich Hertz (German, 1857–1894) produced, detected, and measured electromagnetic waves, specifically radio waves, making him also the true original inventor of radio transmitters and receivers (Fig. 6.25). Unfortunately Hertz died very young; otherwise he would likely have played even more of a role (and been recognized much more) in the early development of radio technology. Because Hertz died before the first Nobel Prizes were awarded in 1901, he was not eligible for the Nobel; nonetheless, the Nobel committee publicly praised his discoveries when they awarded other scientists (see below and p. 867).

Nikola Tesla (Serbo-Croatian, educated in Austria, 1856–1943) publicly demonstrated a radio transmitter and receiver in 1891, and a tunable transmitter and receiver in 1893 in St. Louis (Fig. 6.26). Tesla biographer Margaret Cheney listed some of the key technical features of Tesla's 1893 public demonstration [Cheney 1981, p. 69]:

> Although the St. Louis demonstration was no "message sent 'round the world" as Tesla would doubtless of course have preferred it to be, he had nevertheless demonstrated all the fundamental principles of modern radio: 1. an antenna or aerial wire; 2. a ground connection; 3. an aerial-ground circuit containing inductance and capacity; 4. adjustable inductance and capacity (for tuning); 5. sending and receiving sets tuned to resonance with each other; and 6. electronic tube detectors.

Tesla's 1893 lecture was published and translated around the world. Apparently it was the direct inspiration for Guglielmo Marconi (Italian, 1874–1937) to repeat part of Tesla's experiments a few years later, albeit in a much cruder and less effective fashion [Cheney 1981, p. 69]. A series of court cases over radio patents ultimately proved that Tesla's public disclosures, publications, and discoveries predated and directly informed Marconi's claims [Cheney 1981, p. 176–184; Cheney and Uth 1999, pp. 67–73]. Yet while Tesla continued working on his inventions, Marconi went on a lengthy public tour of self-promotion in Europe. As a result, Marconi was awarded a Nobel Prize for his "discovery," Tesla was not, and Marconi has been erroneously considered worldwide to be the inventor of radio.

Tesla further showed that radio waves transmit not only signals but large amounts of power over considerable distances [Cheney 1981; Cheney and Uth 1999; Tesla 1893, 1904, 1919, 1940]. Tesla also demonstrated a radio-controlled boat in 1898 (p. 1216) and invented many other electrical devices (p. 963).

Beginning in 1897, Karl Ferdinand Braun (German, 1850–1918) developed improved radio transmitters and receivers (Fig. 6.27), as well as phased array antennas. He also invented semiconductor diodes (p. 1054), cathode ray tubes, and oscilloscopes (p. 1009). For his work developing and improving radio technology, he won the Nobel Prize in Physics in 1909. H. Hildebrand, President of the Royal Swedish Academy of Sciences, praised both Braun's innovations and the earlier discoveries by Hertz [https://www.nobelprize.org/prizes/physics/1909/ceremony-speech/]:

> [I]t was Hertz who through his classical experiments showed that the new ideas as to the nature of electricity and light had a real basis in fact. To be sure, it was already well known before Hertz's time, that a capacitor charged with electricity can under certain

> circumstances discharge itself oscillatorily, that is to say, by electric currents passing to and fro. Hertz, however, was the first to demonstrate that the effects of these currents propagate themselves in space with the velocity of light, thereby producing a wave motion having all the distinguishing characteristics of light. This discovery—perhaps the greatest in the field of physics throughout the last half-century—was made in 1888. It forms the foundation, not only for modern science of electricity, but also for wireless telegraphy. But it was still a great step from laboratory trials in miniature where the electrical waves could be traced over but a small number of metres, to the transmission of signals over great distances. [...]
>
> The electrical oscillations sent out from the transmitting station were relatively weak and consisted of wave-series following each other, of which the amplitude rapidly fell-so-called "damped oscillations". A result of this was that the waves had a very weak effect at the receiving station, with the further result that waves from various other transmitting stations readily interfered, thus acting disturbing at the receiving station. It is due above all to the inspired work of Professor Ferdinand Braun that this unsatisfactory state of affairs was overcome. Braun made a modification in the layout of the circuit for the despatch of electrical waves so that it was possible to produce intense waves with very little damping. It was only through this that the so-called "long-distance telegraphy" became possible, where the oscillations from the transmitting station, as a result of resonance, could exert the maximum possible effect upon the receiving station. The further advantage was obtained that in the main only waves of the frequency used by the transmitting station were effective at the receiving station. It is only through the introduction of these improvements that the magnificent results in the use of wireless telegraphy have been attained in recent times.

Adolf Slaby (German, 1849–1913) and Georg von Arco (German, 1869–1940), shown in Fig. 6.28, developed radio systems from 1897 onward. They founded and ran radio research and development departments first at AEG and then at Telefunken.

By harnessing radio waves, Christian Hülsmeyer (German, 1881–1957) invented and demonstrated radar in 1903 (p. 1228). He also patented a radio remote control system in 1904.

Ernst Walter Ruhmer (German, 1878–1913) invented a number of electrical communications devices, collaborating with Salomon Kalischer (German, 1845–1924) and Adolf Pieper (German, 18??–19??) on some of them. In 1904, Ruhmer demonstrated a radiotelephone transmitter and receiver capable of sending the first intelligible voice signals (Fig. 6.29).

Vacuum tube technology evolved from the work of a series of German-speaking scientists, including Julius Plücker (German states, 1801–1868), Heinrich Geissler (German, 1814–1879), Johann Hittorf (German, 1824–1914), Eugen Goldstein (German, 1850–1930), Arthur Wehnelt (German, 1871–1944), and others. See Fig. 6.18.

In 1906, Robert von Lieben (Austrian, 1878–1913), Eugen Reisz (Austrian, 18??–19??), and Siegmund Strauss (Austrian, 18??–19??) invented and demonstrated the triode vacuum tube amplifier (Fig. 6.30). It greatly improved the performance of radio circuits.

No later than 1912, Alexander Meißner (Austrian, 1883–1958) invented, demonstrated, and patented the first modulated, amplified radio systems for high-quality transmission of voices and music. See Fig. 6.31.

Eugen Nesper (German, 1879–1961, Fig. 6.32) conducted experiments with radio transmitters and receivers from 1897 onward. Early in his career, he worked with Adolf Slaby and Georg von Arco. Among other accomplishments, he developed and demonstrated a radio receiver with a powerful seven-tube amplifier in 1923.

Hans Bredow (German, 1879–1959, Fig. 6.32) worked with electrical systems, especially radio, from 1900 onward. Throughout his long career, he was a strong proponent of public radio broadcasting systems in Germany.

6.3.4 Mobile Telephone Systems

By combining telephone and radio technologies, German-speaking scientists invented and commercialized the world's first mobile telephone system. As shown in Fig. 6.33, such mobile phones consisted of telephones and compact radio transmitter boxes, and were installed in German passenger trains (the system was called Zugpostfunk or Zugtelefon). Transmitter/receiver towers near the track connected the train mobile phones to the normal wired telephone network, allowing passengers on trains to call (or receive calls from) people who either were not on trains or were on other trains. Development of the system began during World War I, and the service was commercialized and in service by January 1926. After World War II, the United States copied this mobile telephone system and installed it in U.S. trains. Ultimately mobile telephone technology was miniaturized using microelectronics components and methods that had also been invented in the German-speaking world (Section 6.5 and Appendix B).

6.3.5 Optical Communications Systems

German-speaking scientists also developed systems for transmitting and receiving voices and data via light signals. See p. 1140.

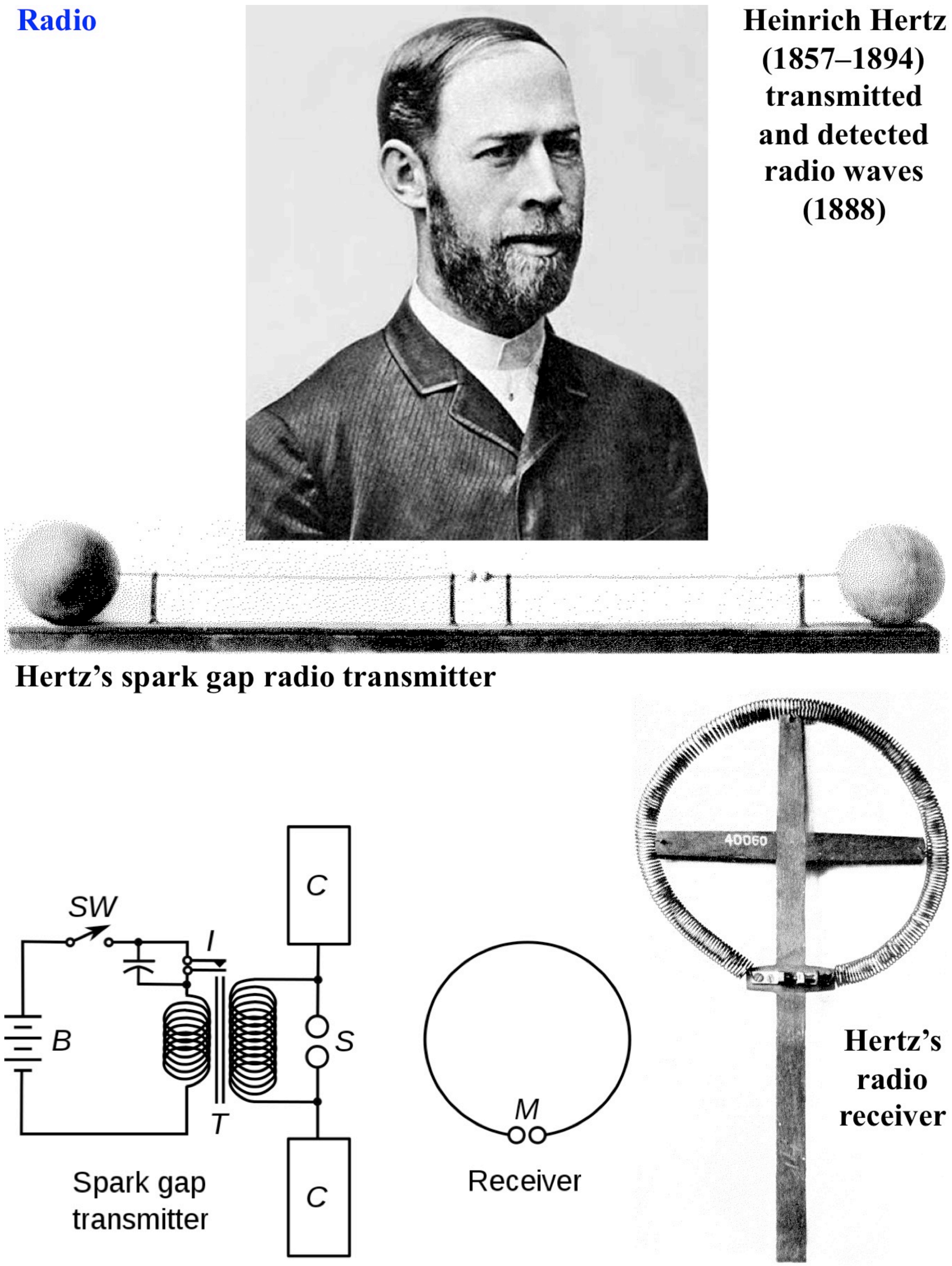


Figure 6.25: Heinrich Hertz transmitted and detected radio waves in 1888.

Nikola Tesla (1856–1943) publicly demonstrated a radio transmitter and receiver in 1891, and a tunable transmitter and receiver in 1893

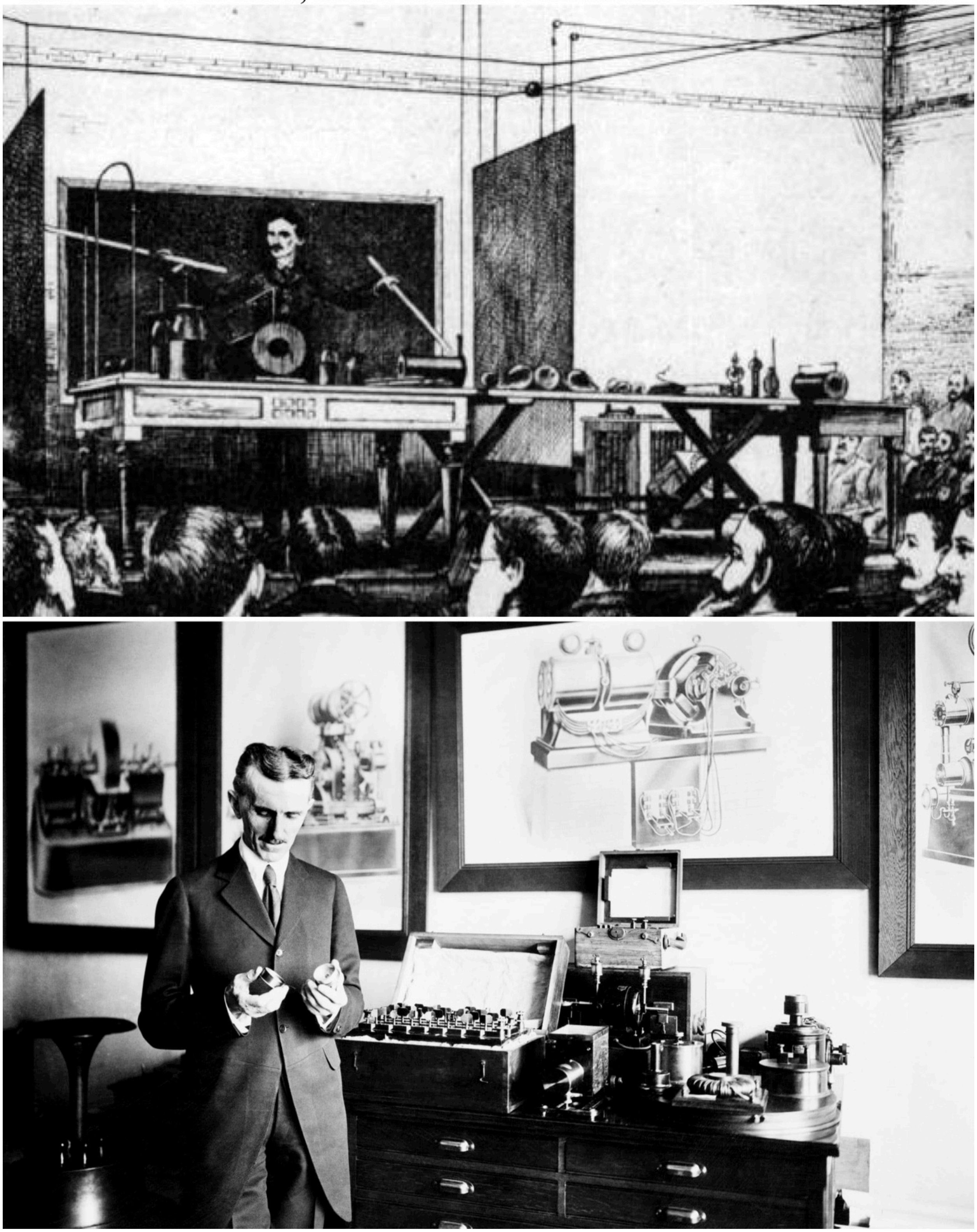


Figure 6.26: Nikola Tesla publicly demonstrated a radio transmitter and receiver in 1891, and a tunable transmitter and receiver in 1893.

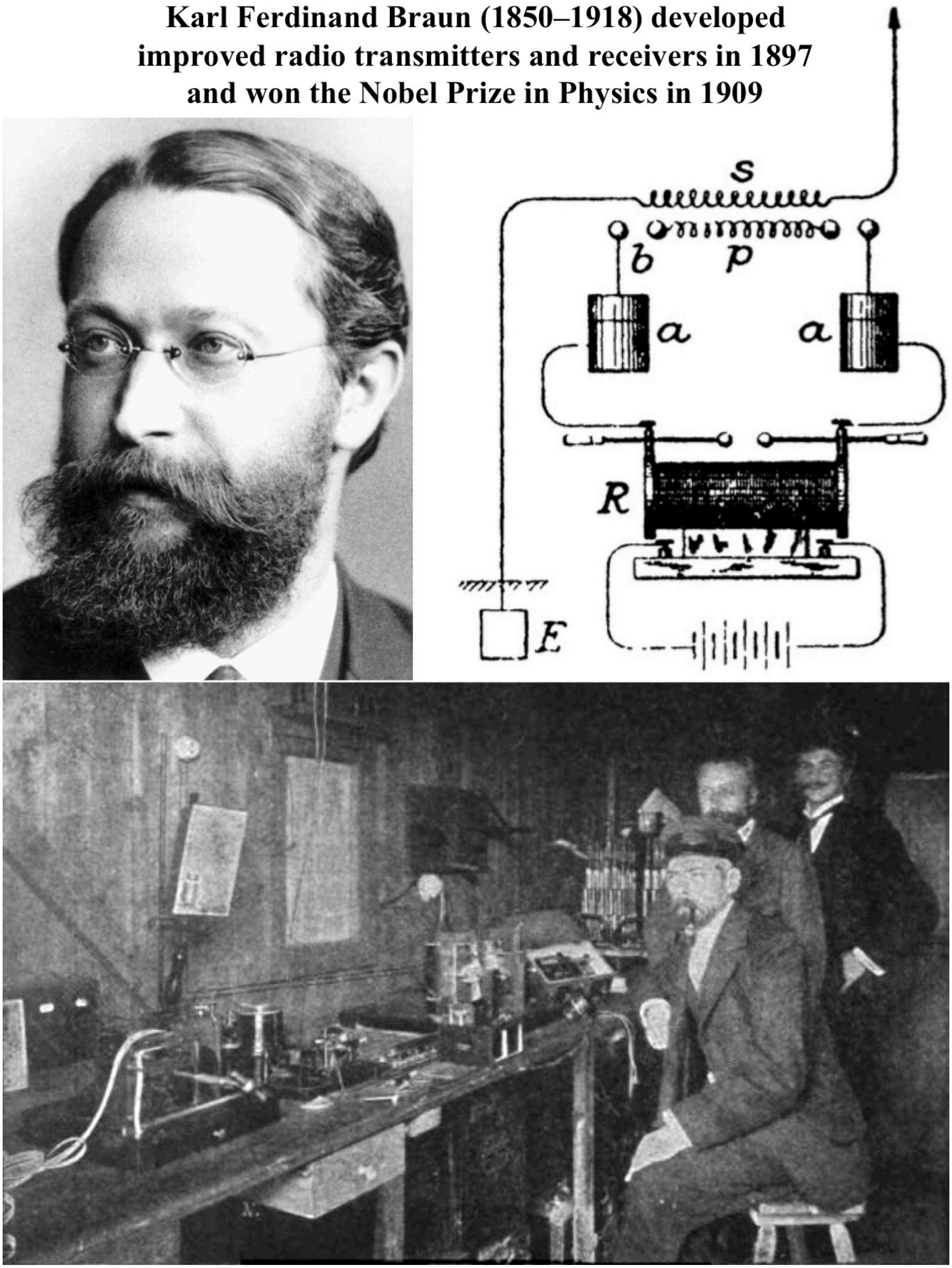
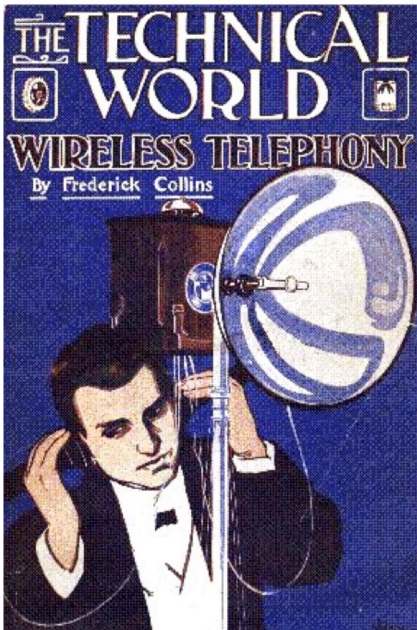


Figure 6.27: Karl Ferdinand Braun developed improved radio transmitters and receivers in 1897 and won the Nobel Prize in Physics in 1909.

Figure 6.28: Adolf Slaby and Georg von Arco developed radio systems from 1897 onward. They founded and ran radio research and development departments at AEG and Telefunken.

Radio

Ernst Ruhmer (1878–1913) | **Salomon Kalischer (1845–1924)** | **Adolf Pieper (18??–19??)**



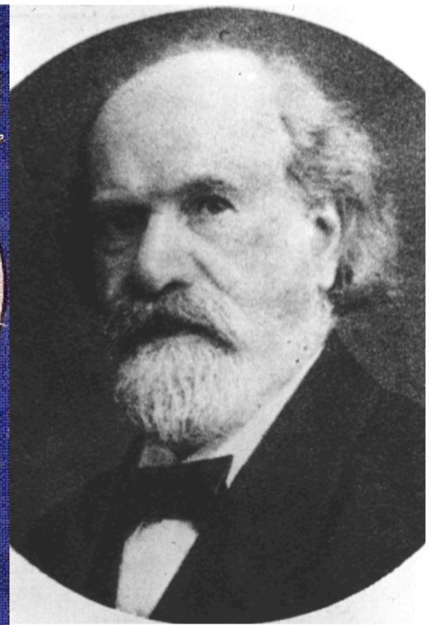
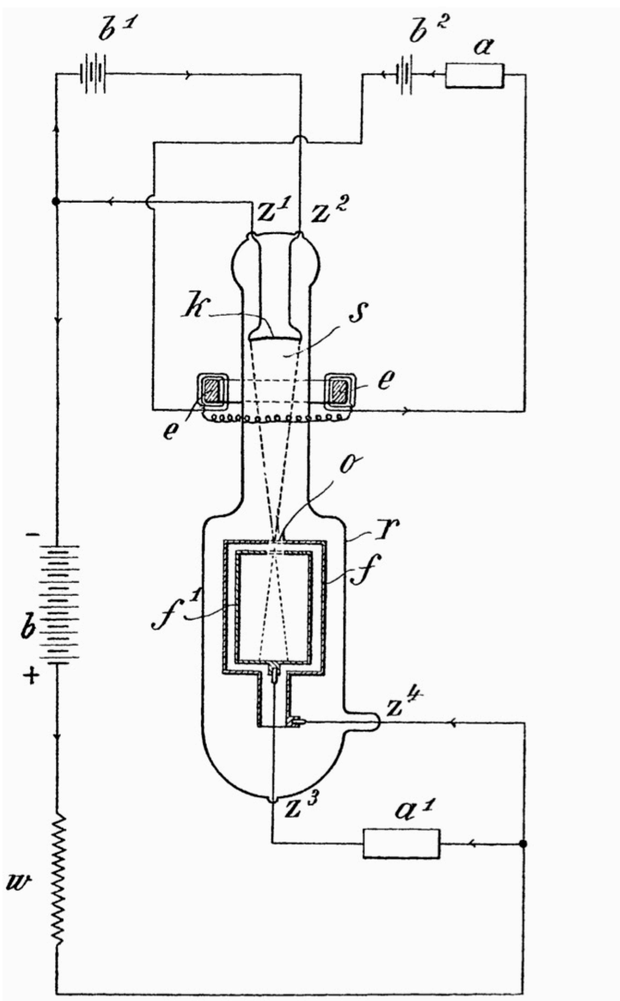


Figure 6.29: Ernst Ruhmer invented a number of electrical communications devices, collaborating with Salomon Kalischer and Adolf Pieper on some of them. In 1904, Ruhmer demonstrated a radiotelephone transmitter and receiver capable of sending the first intelligible voice signals.

Robert von Lieben (1878–1913) invented the triode vacuum tube amplifier (1906)



KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 19. NOVEMBER 1906.

PATENTSCHRIFT

— № 179807 —

KLASSE 21g. GRUPPE 4.

ROBERT VON LIEBEN IN WIEN.

Kathodenstrahlenrelais.

Patentiert im Deutschen Reiche vom 4. März 1906 ab.

Die vorliegende Erfindung bezweckt, mittels Stromschwankungen kleiner Energie solche von großer Energie auszulösen, wobei Frequenz und Kurvenform der ausgelösten Stromschwankungen denen der auslösenden entsprechen.

Die diesem Zweck entsprechende Relaisanordnung ermöglicht es, durch die Wahl der Stärke des durch eine Entladungsröhre fließenden Stromes die im beeinflussenden Stromkreise vorhandenen Energiemengen zu multiplizieren und eignet sich daher für alle Fälle, wo eine derartige Multiplikation innerhalb weiter Grenzen gefordert wird. Insbesondere für manche Probleme der Telephonie (Übertragung der Sprache auf große Entfernungen, Kabeltelephonie, drahtlose Telephonie, Verstärkung der Sprach- und Musikübertragung usw.) kann die Anwendung dieses Relais von Vorteil sein; ferner auch für manches Problem der Fernphotographie, Phonographie usw.

Um diesen Zweck zu erreichen, wird die von Wehnelt gefundene Eigenschaft glühender Metalloxyde benutzt, im Vakuum als Kathoden bei verhältnismäßig niedrigen Potentialen (etwa 200 Volt) Kathodenstrahlen zu emittieren. Die so erzeugten Kathodenstrahlen besitzen geringe Geschwindigkeit und werden daher schon von schwachen magnetischen oder elektrostatischen Feldern stark abgelenkt. Diese Kathodenstrahlen befinden sich hier in dem zu beeinflussenden Stromkreise und werden durch die schwachen Stromschwankungen eines zweiten unabhängigen Stromkreises magnetisch oder elektrostatisch verschieden stark abgelenkt. Diese Ablenkungen bewirken nun durch die Wahl der im folgenden beschriebenen Anordnung die gewünschten starken Schwankungen, die im Stromkreis der Kathodenröhre erfolgen.

Letztere besteht nun, wie aus der Zeichnung ersichtlich ist, aus der hoch evakuierten Glasröhre *r*, in welche die zur Erhitzung der Kathode *k* erforderlichen Stromzuführungsdrähte z_1 und z_2 eingeschmolzen sind.

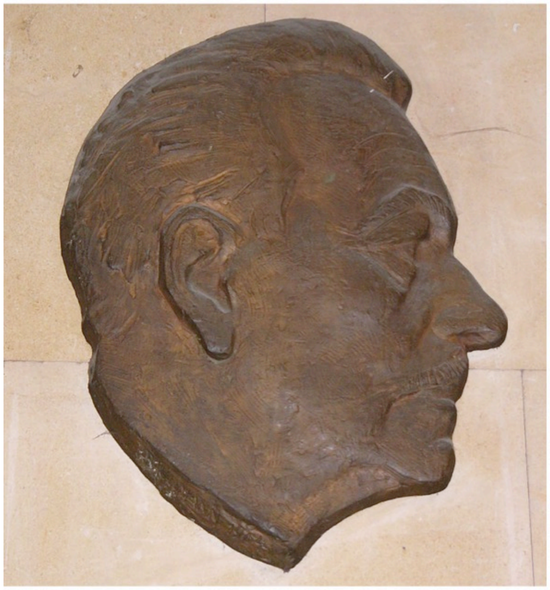
Die Kathode *k* besteht aus einem durch den elektrischen Strom heizbaren, hitzebeständigen Körper, dem die Form eines Hohlspiegels gegeben wird. Die dem Metallkörper *f* zugekehrte Oberfläche dieses Hohlspiegels *k* ist mit einer dünnen Schicht eines nach Wehnelt wirksamen Metalloxydes (*Ca O*, *Ba O* usw.) überzogen. Wird nun das negative Potential der Stromquelle *b* an den beispielsweise durch die Batterie b_1 elektrisch geheizten Hohlspiegel *k* angelegt, so entsendet derselbe Kathodenstrahlen, die sich in einem Brennpunkte (oder in einer Brennlinie) schneiden. Wie man sieht, fällt dieser Brennpunkt in die Öffnung *o* des Faradayschen Hohlzylinders *f*. Durch diese Öffnung gelangen die Strahlen weiter in den inneren Hohlzylinder f_1. Beide Hohlzylinder sind konzentrisch, voneinander elektrisch isoliert und durch die eingeschmolzenen Zuführungsdrähte z_3 z_4 nach außen abgeleitet. Wie die Schaltung zeigt, führt z_4 (unter Vorschaltung eines passenden Widerstandes *w*) direkt, z_3 unter Zwischenschaltung eines für Strom-

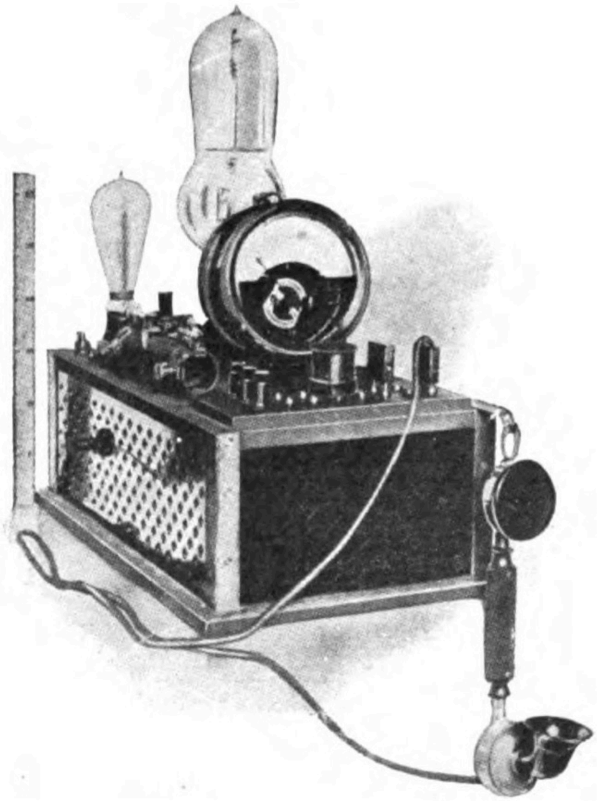
Zu der Patentschrift

№ 179807.

Figure 6.30: Robert von Lieben, Eugen Reisz, and Siegmund Strauss invented and demonstrated the triode vacuum tube amplifier in 1906. It greatly improved the performance of radio circuits.

Alexander Meißner (1883–1958) invented, demonstrated, and patented the first modulated, amplified radio systems for high-quality transmission of voices and music (1912)





AUSGEGEBEN AM 23. JUNI 1919

REICHSPATENTAMT.

PATENTSCHRIFT

— № 291604 —

KLASSE 21a GRUPPE 66

GESELLSCHAFT FÜR DRAHTLOSE TELEGRAPHIE M. B. H. IN BERLIN.

Einrichtung zur Erzeugung elektrischer Schwingungen.

Patentiert im Deutschen Reiche vom 10. April 1913 ab.

Die vorliegende Erfindung betrifft eine Einrichtung zur Erzeugung elektrischer Schwingungen, die darauf beruht, daß ein oder mehrere Schwingungskreise mit einem elektrischen Relais, dessen die Relaiswirkung ausübendes Mittel aus Kathodenstrahlen oder einem ionisierenden Gas o. dgl. besteht, so verbunden wird, daß die in den Schwingungskreisen durch irgendwelche Stöße oder andere Mittel hervorgerufenen Anfangsschwingungen dem Relais zugeführt werden und die von diesem verstärkten Ströme wieder auf die Schwingungskreise einwirken, wodurch die Amplitude der Eigenschwingung der Kreise erhöht wird. Da der wirksame Bestandteil dieser Relais im Gegensatz zu mechanisch arbeitenden keine Masse besitzt, so ist es gerade mit diesem Relais möglich, elektrische Schwingungen bis zu den höchsten Frequenzen in der angegebenen Einrichtung zu erzeugen und da die Frequenz der Schwingungen nur durch die Eigenschwingung des Schwingungssystems bedingt ist, und im Relais andererseits keine störenden Einflüsse sich geltend machen, so erzielt man mit dieser Einrichtung zum ersten Mal ungedämpfte Schwingungen von absolut konstanter Schwingungszahl und Amplitude.

Eine z. B. für diesen Zweck sehr geeignete Form dieser Relais besteht aus einem ganz oder teilweise evakuierten oder mit Gasen oder Dämpfen unter geringem Druck gefüllten Glasgefäß, das eine erhitzte Kathode und eine oder mehrere Anoden enthält. Die von der Kathode ausgehenden Kathodenstrahlen sind entweder selbst das wirksame Agens oder bewirken eine Ionisation des Gases, so daß ein dauernder Stromweg im Relais hergestellt wird. Die zu verstärkenden Ströme können der erhitzten Kathode und einer Hilfsanode (Primärseite des Relais) zugeführt werden. Die verstärkten Ströme treten dann in dem über die Kathode und Hauptanode (Sekundärseite) geführten Stromkreis auf, wobei die vermehrte Energie dieser Ströme aus der den Dauerstrom liefernden Stromquelle entsteht.

Eine Ausführungsform der Schaltung unter Zugrundelegung eines solchen Relais ist in der Figur dargestellt.

1 ist das Kathodenstrahlrelais, das die von der Batterie 2 geheitzte Kathode 3 und die Anode 4 enthält. 5 ist eine Hilfselektrode, die mit der Kathode 3 über die Kopplungsspule 6 leitend verbunden ist. 7 ist ein Schwingungskreis, der aus dem Kondensator 8 und den beiden Selbstinduktionen 9 und 10 besteht. Dieser Schwingungskreis 7 steht einerseits mit der Anode 4 und andererseits, über die Stromquelle 11, mit der Kathode 3 in Verbindung. Der Schwingungskreis 7 ist also sowohl mit der Primär-, wie mit der Sekundärstrecke des Relais gekoppelt. 12 ist eine Drosselspule, die gemeinsam mit der Kapazität 13 erforderlich ist, sofern als Stromquelle 11 nicht eine Batterie, sondern eine Maschine zur Speisung des Entladungsrohres 1 benutzt wird. In diesem Fall dient die Einrichtung dazu, die störenden Wirkungen des

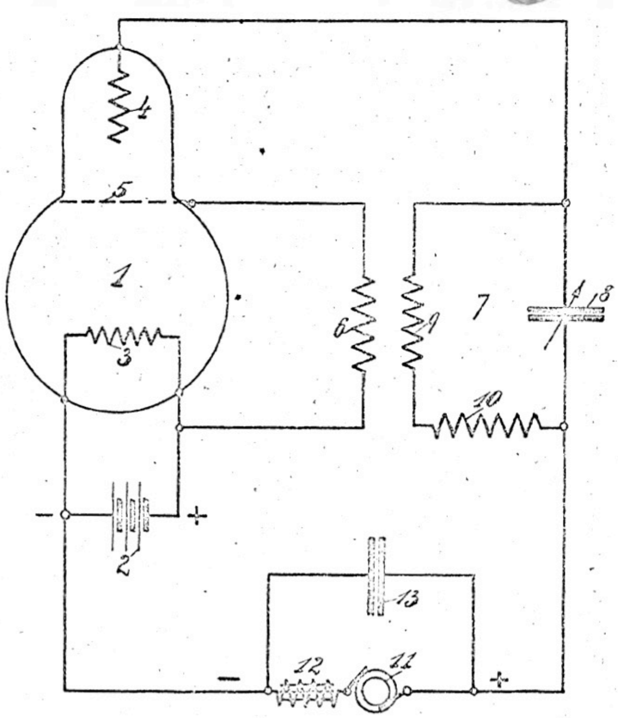


Figure 6.31: No later than 1912, Alexander Meißner invented, demonstrated, and patented the first modulated, amplified radio systems for high-quality transmission of voices and music.

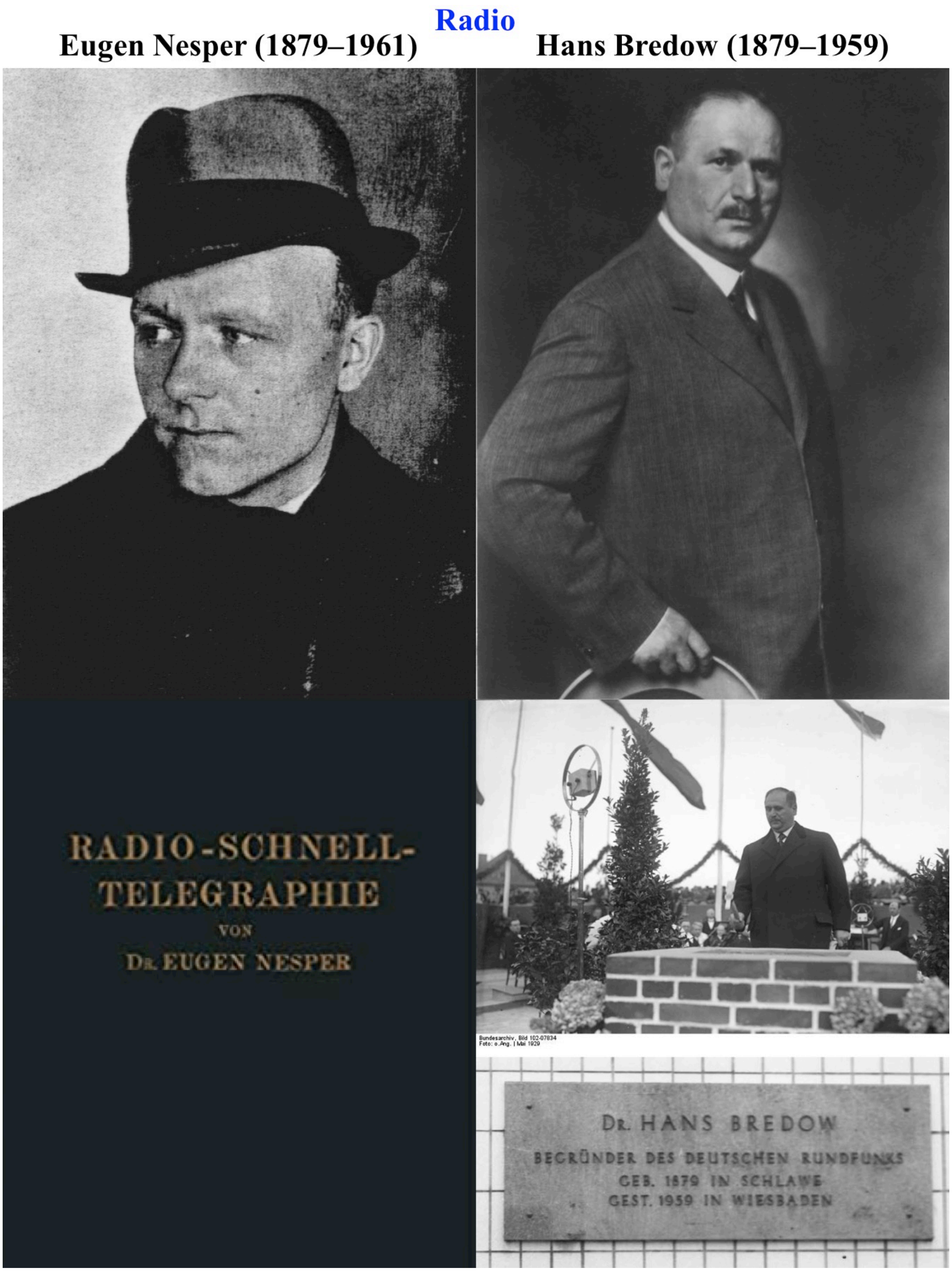


Figure 6.32: Some other important early radio pioneers included Eugen Nesper and Hans Bredow.

Figure 6.33: The world's first mobile telephone system began commercial operation on German trains in 1926.

6.3.6 Disc Phonograph Records and Players

Emil(e) Berliner (German, 1851–1929) was educated in Germany and then moved to the United States. In 1886, he invented disc phonograph records and the corresponding player, which he called the Gramophone (Fig. 6.34). Earlier phonographs had used cylinders made of wax, which were quite cumbersome in shape and also very fragile and temperature sensitive. Berliner's flat discs made of hard rubber were durable recordings that could be easily stored, stacked, played, and flipped. Berliner also developed improved microphones, acoustic tile, and an improved loom for producing cloth, and he experimented with proto-helicopters and autogyros (p. 1816).

6.3.7 Magnetic Tape Recording

Fritz Pfleumer (Austrian, 1881–1945), Walter Weber (German, 1907–1944), and Hans-Joachim von Braunmühl (German, 1900–1980) developed magnetic plastic tape recorders, dubbed the Magnetophon, with the first demonstration in 1927 [Albert 2014]. See Fig. 6.35. Weber and von Braunmühl also invented improved designs for microphones.

German-speaking creators also developed a magnetic tape recorder that used steel tape instead of plastic tape. In 1930, Kurt Stille (German, 1873–1957) and Ludwig Blattner (German, 1881–1935) invented the Blattnerphone magnetic steel tape recorder, shown in Fig. 6.36. However, the advantages of the plastic tape soon won out.

Magnetic tape recording technology was transferred to other countries after World War II. For example, BIOS 951, *The Magnetophon Sound Recording and Reproducing System*, reported:

> This report describes a system for the recording and reproduction of sound, making use of the well-known magnetic principle, which has been developed in Germany both before and during the war. During the war an improvement in performance has been achieved and the quality of reproduction of speech and music now obtainable by means of this system is of a high order and, it is claimed, consistently better than that achieved with other systems.

There were a number of other postwar Allied reports on German magnetic tape recorders, such as BIOS 1379, *Plastics in German Sound Recording Systems*, and FIAT 705, *High Frequency Magnetophone Magnetic Sound Recorders*. In addition to the reports, many magnetic recorders and reels of tape were seized and later copied by Allied countries (Figs. 6.37–6.38). For example, a U.S. Army officer, John T. "Jack" Mullin, confiscated several German Magnetophon units, shipped them to a private address in the United States, and then presented their technology to potential customers and investors as his own invention. Mullin became much more famous and wealthy than the actual German and Austrian inventors, and he was part of a pattern, not an isolated case.

In 1963, small reels of magnetic audio tape were packaged and marketed as "compact cassette tapes" by Philips Eindhoven, and that format was dominant worldwide for over three decades. (For more information on Philips Eindhoven, see p. 1028.)

The Magnetophon is just one example of the revolutionary magnetic recording technologies for audio, video, and data that were invented and perfected in Germany, then transferred to Allied countries in 1945 and used worldwide for decades [Gimbel 1990]. Gunter Guttwein (German, 1906–1978) also developed magnetic recording and magnetic memory technologies in Germany, and brought those to the U.S. Army's Fort Monmouth electronics laboratory after World War II [Fort Monmouth Historical Office 2008].

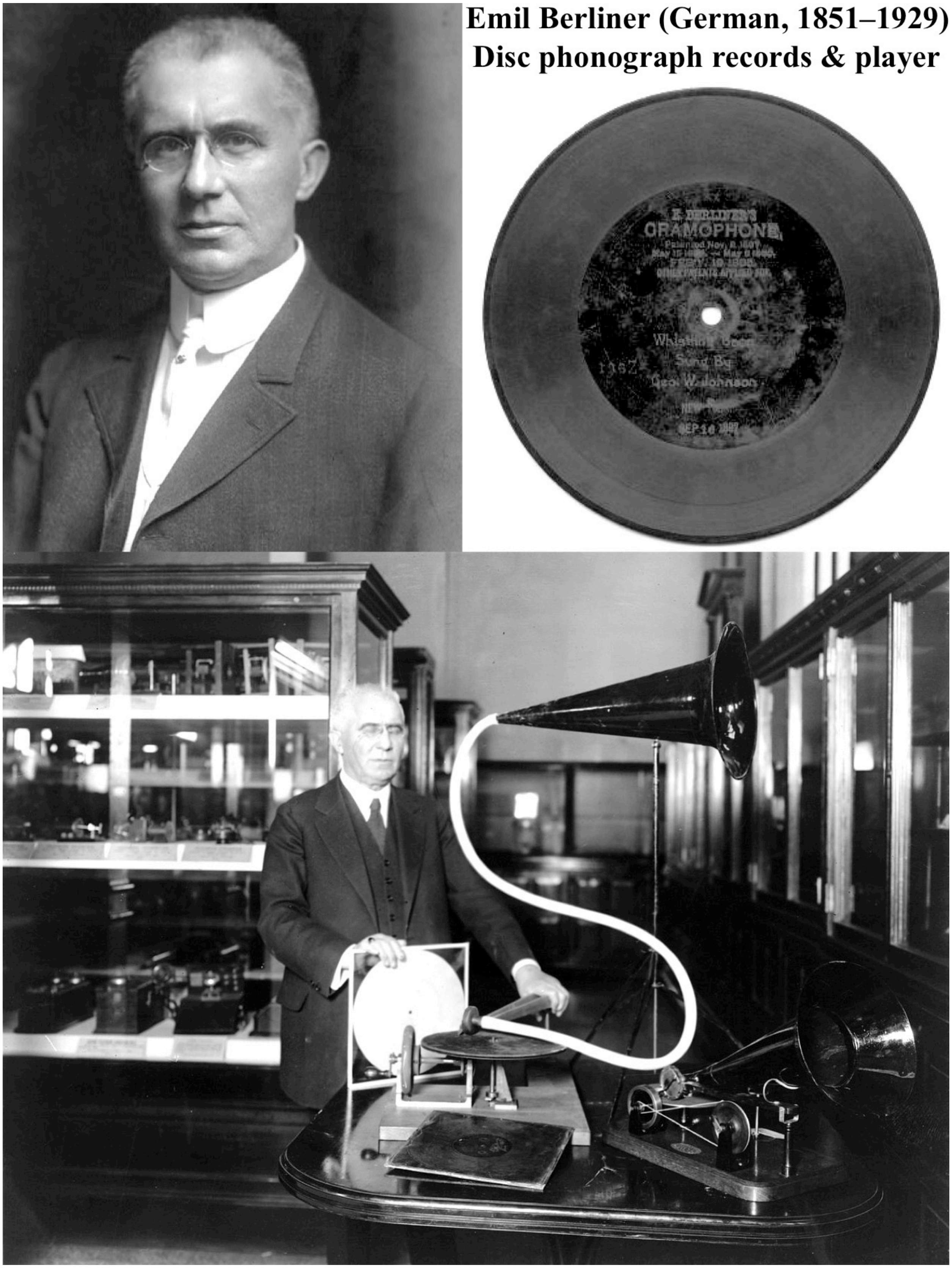


Figure 6.34: Emil(e) Berliner invented the disc phonograph record and player in 1886.

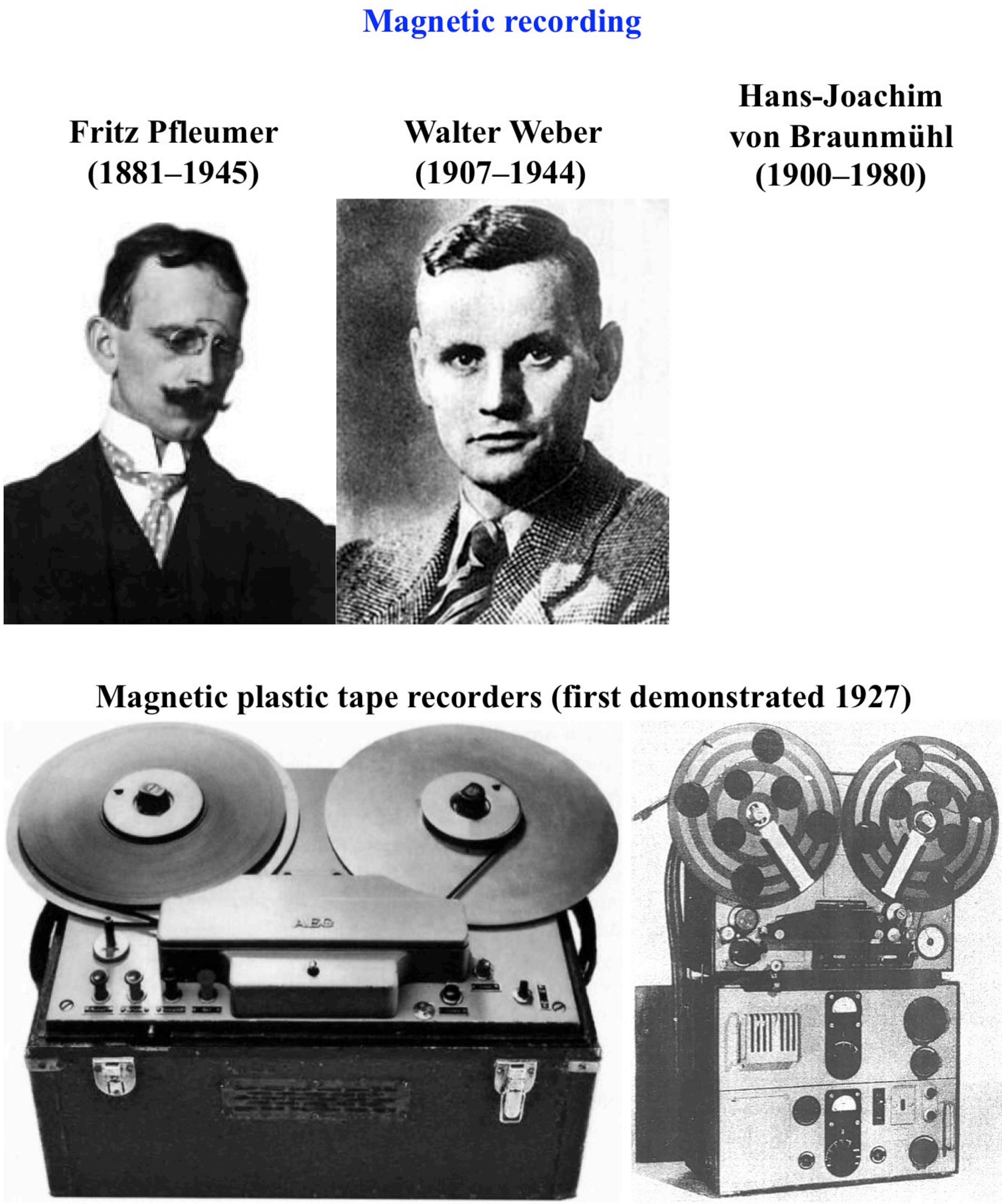


Figure 6.35: Fritz Pfleumer, Walter Weber, and Hans-Joachim von Braunmühl developed magnetic plastic tape recorders (first demonstrated in 1927).

Magnetic recording

Kurt Stille (1873–1957)

Ludwig Blattner (1881–1935)

Blattnerphone magnetic steel tape recorder (1930)

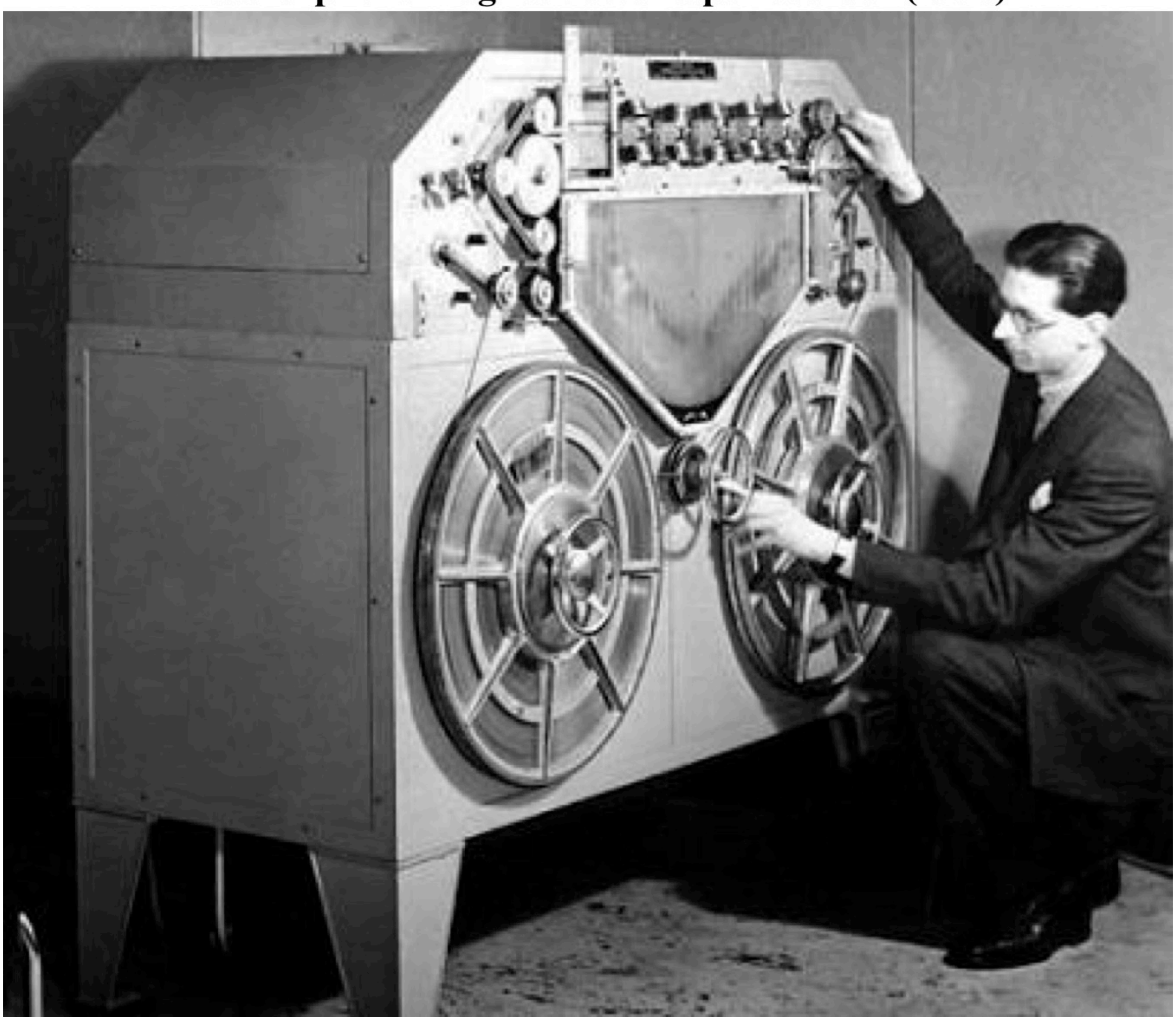


Figure 6.36: Kurt Stille and Ludwig Blattner developed the Blattnerphone magnetic steel tape recorder (1930).

**NARA RG 40, Entry UD-75, Box 58,
Folder Replies to Letters of April 29, 1947**

Figure 6.37: After World War II, German magnetic tape recorders, tape, and designs were taken by the United States and directly copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder Replies to Letters of April 29, 1947].

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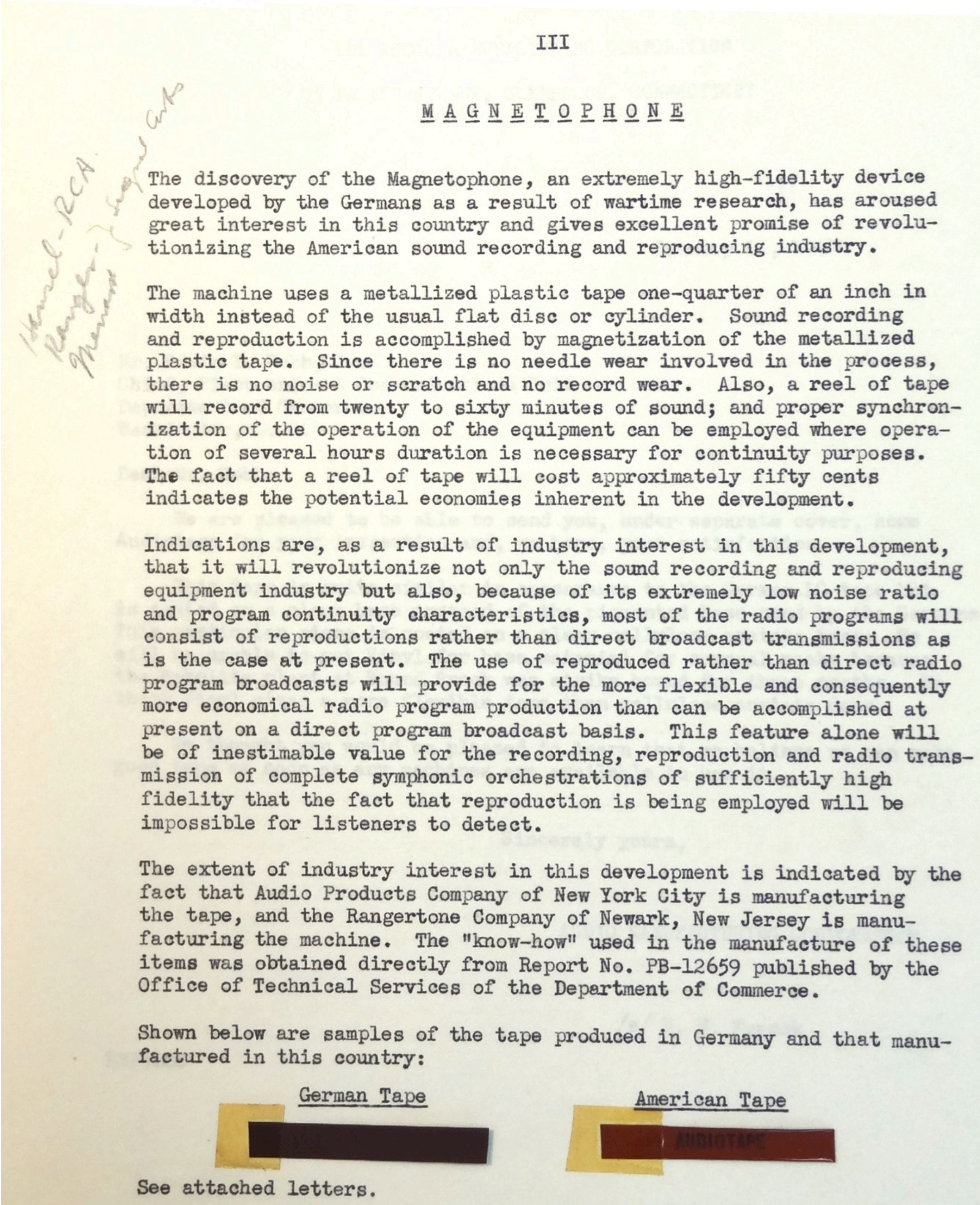
NARA RG 40, Entry UD-75,
Box 58, Folder TIID Discards



III

MAGNETOPHONE

The discovery of the Magnetophone, an extremely high-fidelity device developed by the Germans as a result of wartime research, has aroused great interest in this country and gives excellent promise of revolutionizing the American sound recording and reproducing industry.

The machine uses a metallized plastic tape one-quarter of an inch in width instead of the usual flat disc or cylinder. Sound recording and reproduction is accomplished by magnetization of the metallized plastic tape. Since there is no needle wear involved in the process, there is no noise or scratch and no record wear. Also, a reel of tape will record from twenty to sixty minutes of sound; and proper synchronization of the operation of the equipment can be employed where operation of several hours duration is necessary for continuity purposes. The fact that a reel of tape will cost approximately fifty cents indicates the potential economies inherent in the development.

Indications are, as a result of industry interest in this development, that it will revolutionize not only the sound recording and reproducing equipment industry but also, because of its extremely low noise ratio and program continuity characteristics, most of the radio programs will consist of reproductions rather than direct broadcast transmissions as is the case at present. The use of reproduced rather than direct radio program broadcasts will provide for the more flexible and consequently more economical radio program production than can be accomplished at present on a direct program broadcast basis. This feature alone will be of inestimable value for the recording, reproduction and radio transmission of complete symphonic orchestrations of sufficiently high fidelity that the fact that reproduction is being employed will be impossible for listeners to detect.

The extent of industry interest in this development is indicated by the fact that Audio Products Company of New York City is manufacturing the tape, and the Rangertone Company of Newark, New Jersey is manufacturing the machine. The "know-how" used in the manufacture of these items was obtained directly from Report No. PB-12659 published by the Office of Technical Services of the Department of Commerce.

Shown below are samples of the tape produced in Germany and that manufactured in this country:

German Tape — American Tape

See attached letters.

Figure 6.38: After World War II, German magnetic tape recorders, tape, and designs were taken by the United States and directly copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

6.3.8 Motion Picture Cameras and Projectors

As shown on p. 640, the brothers Max Skladanowsky (German, 1863–1939) and Emil Skladanowsky (German, 1866–1945) created the Bioscop motion picture camera and projector in 1892 and presented the first public films in 1895.

Methods of recording audio tracks on visual film reels were developed by Josef Benedict Engl (German, 1893–1942), Joseph Massolle (German, 1889–1957), Hans von Ohain (German, 1911–1998), and Hans Vogt (German, 1890–1979).

6.3.9 Television

In the English-speaking world, television is generally regarded as an invention that originated with experiments before World War II by Philo Farnsworth (U.S., 1906–1971), Vladimir Zworykin (Russian but worked in the United States, 1888–1982), and John Logie Baird (Scottish, 1888–1946), and that led to the first major television systems and programs in the 1950s. While those scientists and events were indeed part of the history of television, scientists from the great German-speaking world were responsible for most of the key steps in the development of television, from the earliest experiments through the world's most advanced television systems in 1945 and beyond.

In the first important step toward television development, Julius Plücker (German states, 1801–1868) discovered magnetic deflection of electrons in a vacuum tube in 1857. See Fig. 6.39.

By harnessing Plücker's discovery, Karl Ferdinand Braun (German, 1850–1918) invented and demonstrated cathode ray tubes and oscilloscopes in 1897 (Fig. 6.39). Oscilloscopes are essentially television sets that visually display sine waves corresponding to electrical input signals; they have been used in various forms ever since as important diagnostic and readout instruments for electronic systems. In much of the world, cathode ray tube screens are still called Braun tubes. Braun also invented semiconductor diodes in 1874 (p. 1054) and won the Nobel Prize in Physics in 1909 for his radio-related research (p. 987).

Paul Nipkow (German, 1860–1940, Fig. 6.39) worked on an electromechanical television system that used a "Nipkow disk" to guide its scanning pattern. Nipkow's work greatly facilitated and inspired research by many other scientists after that.

In 1909, Ernst Ruhmer (German, 1878–1913) demonstrated a proof-of-concept 5x5 pixel CCD-like semiconductor television camera and a 5x5 pixel flat-panel television display (Fig. 6.40). He sought funding to build television cameras and displays with 100x100 pixels, but unfortunately he fell ill and died.

Some other early pioneers of television included August Karolus (German, 1893–1972), Kálmán Tihanyi (Hungarian, 1897–1947), Max Knoll (German, 1897–1969, one of the inventors of electron microscopes—see p. 1299), and Erhard Kietz (German, 1909–1982), as shown in Fig. 6.41.

Siegmund Loewe (German, 1885–1962) and Manfred von Ardenne (German, 1907–1997) developed a complete television transmitter and receiver system in 1931, and then an improved and larger television receiver in 1936 (Fig. 6.42). Figure 6.43 also shows a competing Telefunken commercial television receiver from 1933.

Emil Mechau (German, 1882–1945), Walter Heimann (German, 1908–1981), and Werner Flechsig (German, 1900–1981) developed the long-range zoom television cameras that were used to broadcast the 1936 Berlin Olympics (Fig. 6.44).

Fritz Schröter (German, 1886–1973) at Telefunken developed interlaced television scanning and rectangular picture tubes, such as the 1937 television receiver shown in Fig. 6.45; he also did seminal work on pulse code modulation and analog-to-digital converters [FIAT 865]. Fritz Fischer (Swiss, 1898–1947) and Edgar Gretener (Swiss 1902–1958, also important in cryptography) developed television projectors. Friedrich Gladenbeck (German, 1899–1987, also important in robotics, p. 1218) developed high-frequency radio, remote control, and television systems.

Figure 6.46 shows a Telefunken television camera and Einheitsempfänger E1 home receiver, both from 1939. Late 1930s German television broadcasts featured a wide variety of regular news and entertainment shows with 441 horizontal lines of resolution for the height of the picture and 50 interlaced frames per second (25 full frames per second), fully comparable in both quality and content to American television of two decades later [Kloft 2000].

German-speaking scientists miniaturized television systems for use in smart bombs and missiles, decades before that technology became popularized in the first U.S.-Iraq war (pp. 1854–1856, 5482–5487). The same technology was also employed in battlefield robotics (pp. 1218–1219). Figures 6.47–6.49 show a shoebox-sized Fernseh television receiver/picture tube and shoebox-sized Tonne television camera/transmitter that were first operational in 1942.

CIOS XXXII-125, *German Guided Missile Research*, pp. 139–143, described the miniaturized television systems and some of their applications (see pp. 5482–5487):

> 3. Television System for Guided Missiles.
>
> This consists of two units (camera and transmitter) in the missile, and a further two circuits (receiver and indicator) in the controlling aircraft.
>
> All units measure 7" x 7" x 14½". Only the camera and indicator were designed by Fernseh, the radio link being designed by another firm.
>
> In the early models a 441 line interlaced picture was used, the picture frequency being 25 per second (frame frequency 50 per second). [...]
>
> The picture quality obtained would appear to be excellent. Some photographs have been obtained of the picture given by the 441 line interlaced equipment. These pictures were

> taken using the whole equipment, including the radio link, but a large, good quality receiving tube was used. The photographs indicate that the definition was about as good as can be obtained with a 441 line system. [...]
>
> The D.F.S. have been concerned with the testing and installation of the Fernseh television in the Hs 293. [...]
>
> On one test a range of 263 kms. was obtained with the controlling aircraft at a height of 4,000 metres and the bomb at a height of 1,000 metres. [...]
>
> It is understood that the Fernseh television camera using the infra-red tube was also used in the robot tank. [...]
>
> An interesting television camera of very compact design is being developed for Wasserfall. [...]

In "Nazis Had Television Eye to Guide Missile's Path," the *New York Times* reported [NYT 1949-05-22]:

> DAYTON, Ohio, May 21—German scientists during World War II developed a television device similar to the human eye for controlling guided missiles or aircraft but never put it to use, the Air Materiel Command at Wright Field disclosed today.
>
> The device was built into missiles such as bombs and guided them toward a pre-set target without outside help, it was said. It used a movable mirror which reflected the target to a television tube. This tube transmitted electrical impulses to the missile's steering device, keeping the missile constantly pointed at the target.
>
> The pilot aligned his target in the television picture in his sighting mechanism, switched on the bomb's steering device and released the bomb. The missile then was on its own.
>
> The entire device was no bigger than eight inches in diameter and weighed only four pounds. Some were as small as five inches in diameter.

In addition to such military applications, handheld compact video cameras based on this technology were used for many decades after the war.

These wartime video cameras and television receivers could also achieve remarkable resolution. Some systems transmitted images up to 1029 horizontal lines in height at 25 frames per second [Faensen 2001, p. 90], comparable to modern high-definition television (HDTV, 1080 lines) and far greater than the 480-line standard resolution that was used for U.S. commercial television broadcasts until the early 2000s.

Walter Bruch (German, 1908–1990) operated television cameras at the 1936 Berlin Olympics and then developed the color PAL television system after the war. See Fig. 6.50.

Peter Carl Goldmark (Hungarian, 1906–1977) developed magnetic video recording (the Electronic Video Recording system, 1967), as well as LP records and a color television system in the United States (Fig. 6.50).

Robert Adler (Austrian, 1913–2007, Fig. 6.51), a physicist from Vienna, joined Zenith Electronics in the United States in 1941 and patented a huge number of television-related inventions, including remote controls (using ultrasonic or optical signals), subscription television channels (using scrambled and descrambled signals), and color television systems.

German-speaking scientists also invented both light-emitting diodes (LEDs, pp. 1113 and 2900) and liquid crystals (p. 512), which are the basis of modern video screens.

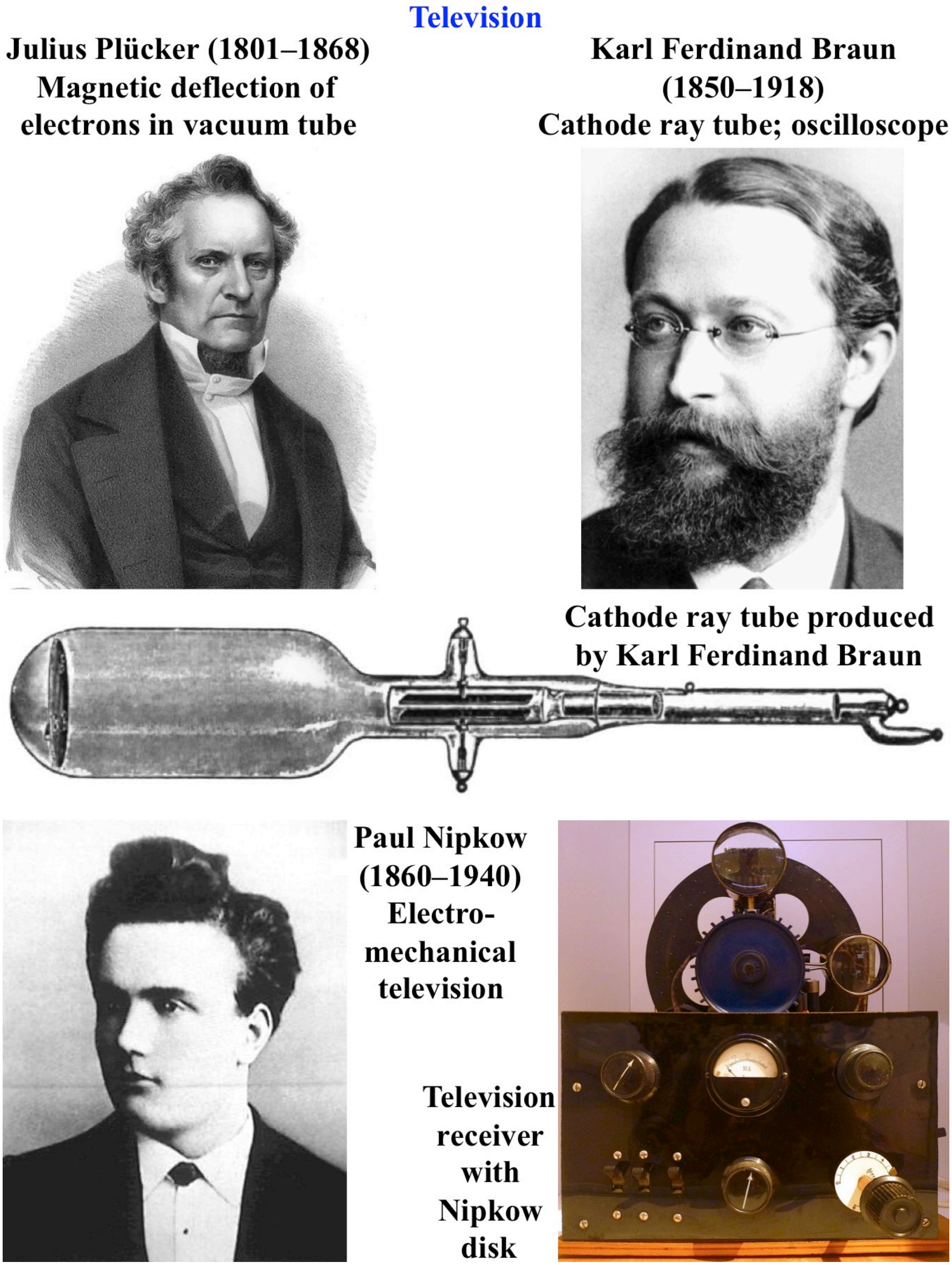


Figure 6.39: In the first steps toward television development, Julius Plücker discovered magnetic deflection of electrons in a vacuum tube, Karl Ferdinand Braun created cathode ray tubes and oscilloscopes, and Paul Nipkow worked on an electromechanical television system that used a "Nipkow disk" to guide its scanning pattern.

Television

Ernst Ruhmer (1878–1913) demonstrated a proof-of-concept 5x5 pixel CCD-like semiconductor television camera and a 5x5 pixel flat-panel television display (1909). He sought funding to build television cameras and displays with 100x100 pixels, but unfortunately he fell ill and died.

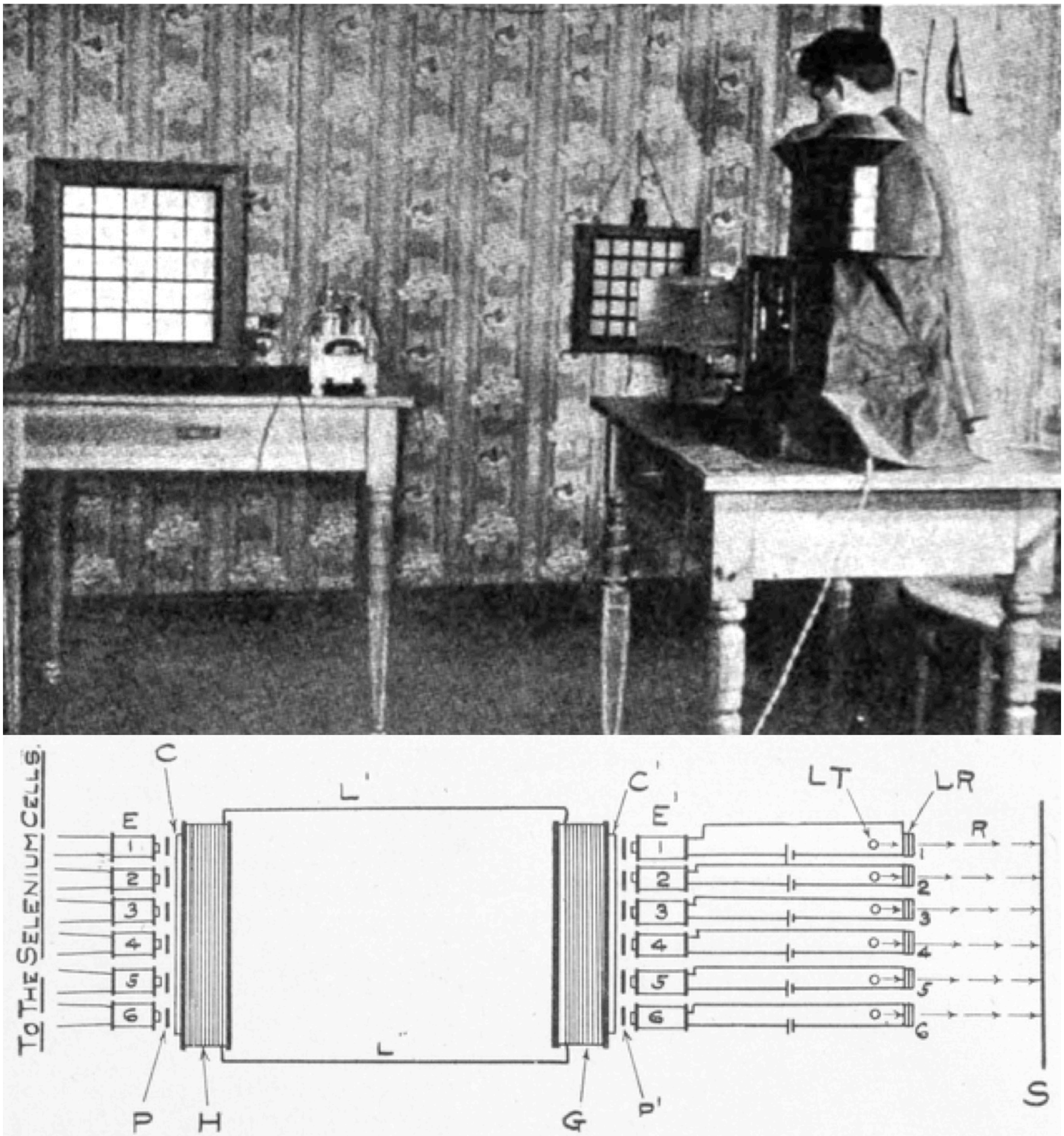


Figure 6.40: In 1909, Ernst Ruhmer demonstrated a proof-of-concept 5x5 pixel CCD-like semiconductor television camera and a 5x5 pixel flat-panel television display [Gernsback 1909]. He sought funding to build television cameras and displays with 100x100 pixels, but unfortunately he fell ill and died.

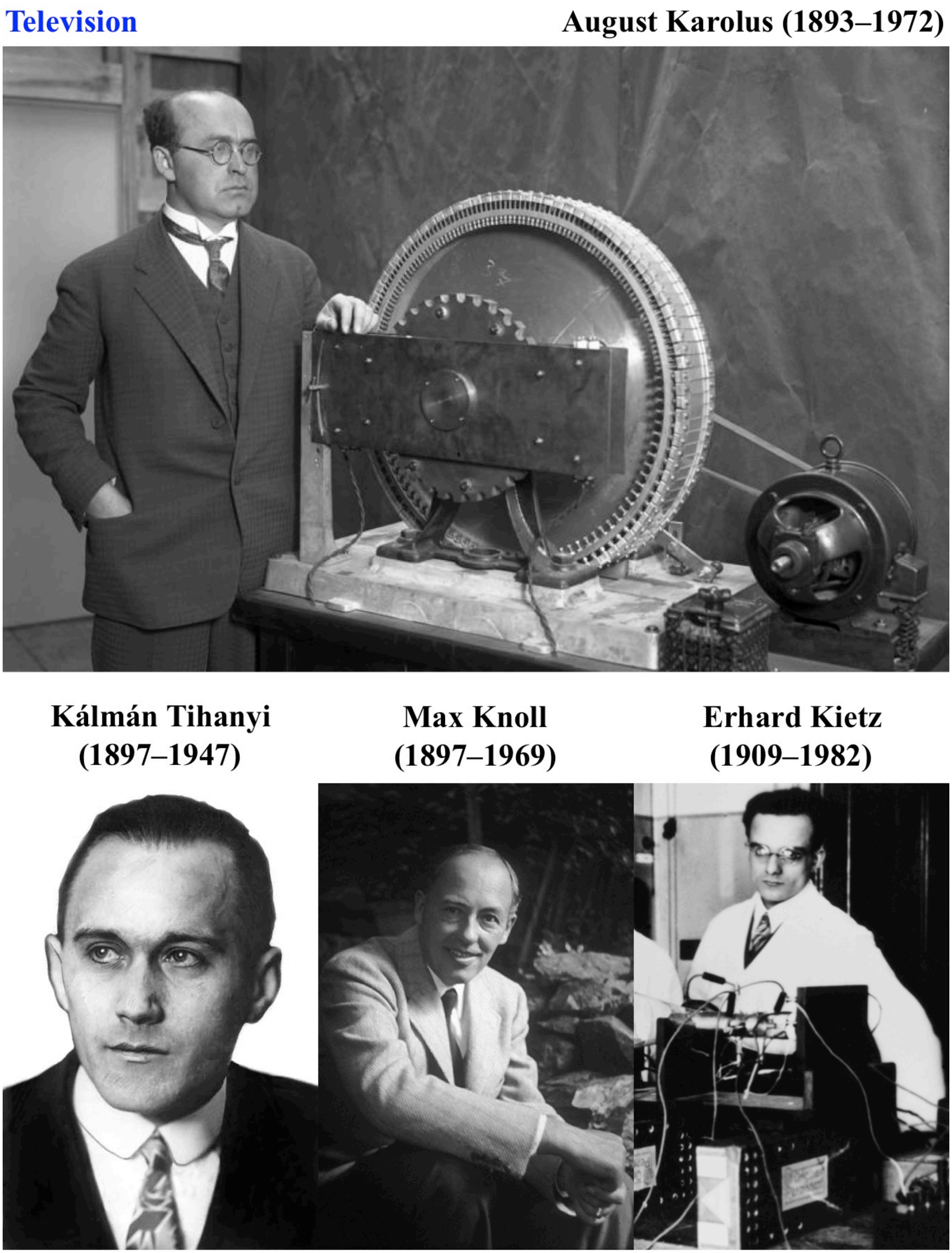
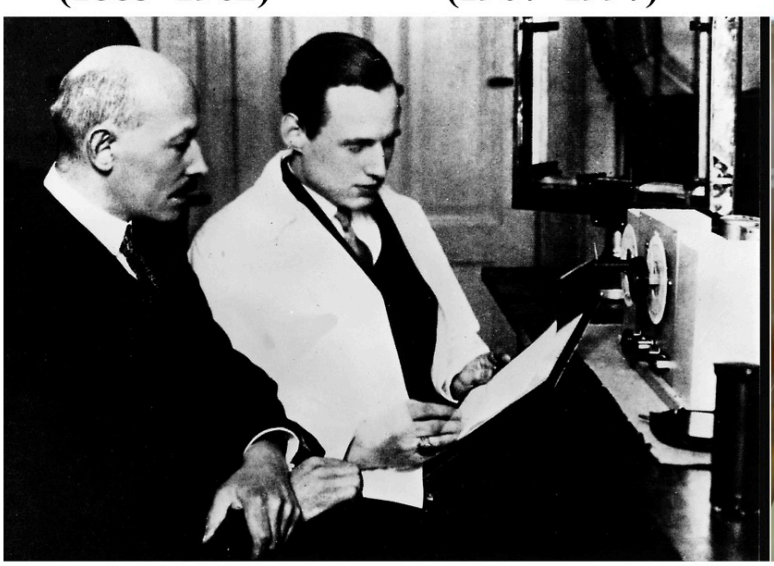


Figure 6.41: Other pioneers of television included August Karolus, Kálmán Tihanyi, Max Knoll, and Erhard Kietz.

Television

Television transmitter and receiver (1931)

Siegmund Loewe (1885–1962) **Manfred von Ardenne (1907–1997)**



Television receiver (1936)

Figure 6.42: Siegmund Loewe and Manfred von Ardenne developed a complete television transmitter and receiver system in 1931 and then an improved and larger television receiver in 1936.

Figure 6.43: Telefunken commercial television receiver in 1933.

Television **1936 Berlin Olympics TV camera with long-range zoom**

Emil Mechau (1882–1945) **Walter Heimann (1908–1981)** **Werner Flechsig (1900–1981)**

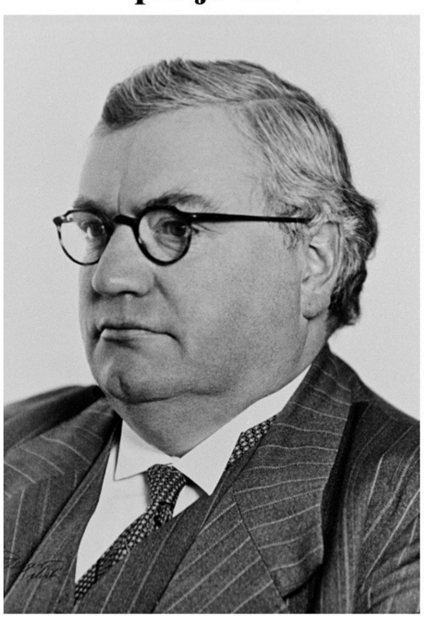
Figure 6.44: Emil Mechau, Walter Heimann, and Werner Flechsig developed the long-range zoom television cameras that were used to broadcast the 1936 Berlin Olympics.

Television

Fritz Schröter (1886–1973)
Interlaced TV scanning;
rectangular tubes

Television receiver (1937)

Fritz Fischer (1898–1947)
Television projector



Edgar Gretener (1902–1958)
Television projector; cryptography

Friedrich Gladenbeck (1899–1987)
High-frequency radio; television

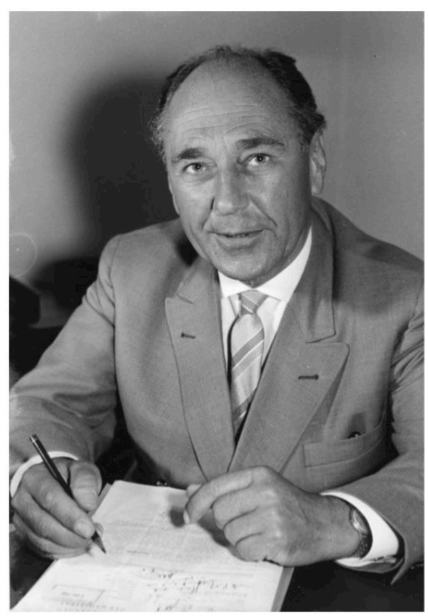


Figure 6.45: Fritz Schröter at Telefunken developed interlaced TV scanning and rectangular picture tubes, such as the 1937 television receiver shown here. Fritz Fischer and Edgar Gretener (also important in cryptography) developed television projectors. Friedrich Gladenbeck (also important in robotics, p. 1218) developed high-frequency radio, remote control, and television systems.

Telefunken TV camera and home TV receiver (1939)

Figure 6.46: Telefunken television camera and Einheitsempfänger E1 home receiver, both from 1939. Late 1930s German television broadcasts featured a wide variety of shows with 441 vertical lines of resolution and 50 interlaced frames per second, comparable in quality to American television of two decades later.

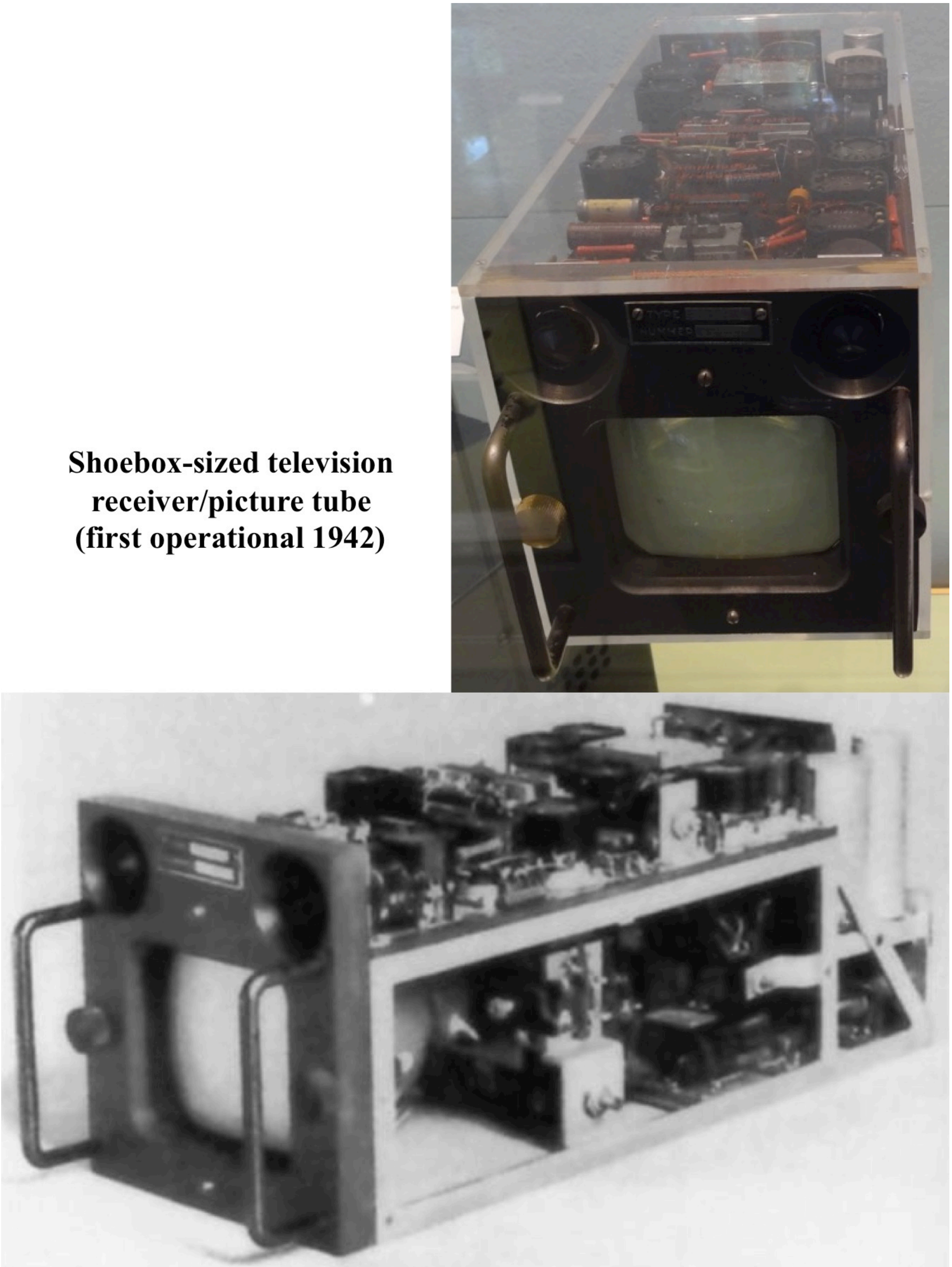


Figure 6.47: German-speaking scientists miniaturized television systems for use in smart bombs and missiles (pp. 1854–1856), as exemplified by this shoebox-sized television receiver/picture tube, which was first operational in 1942. (See also pp. 5482–5487.)

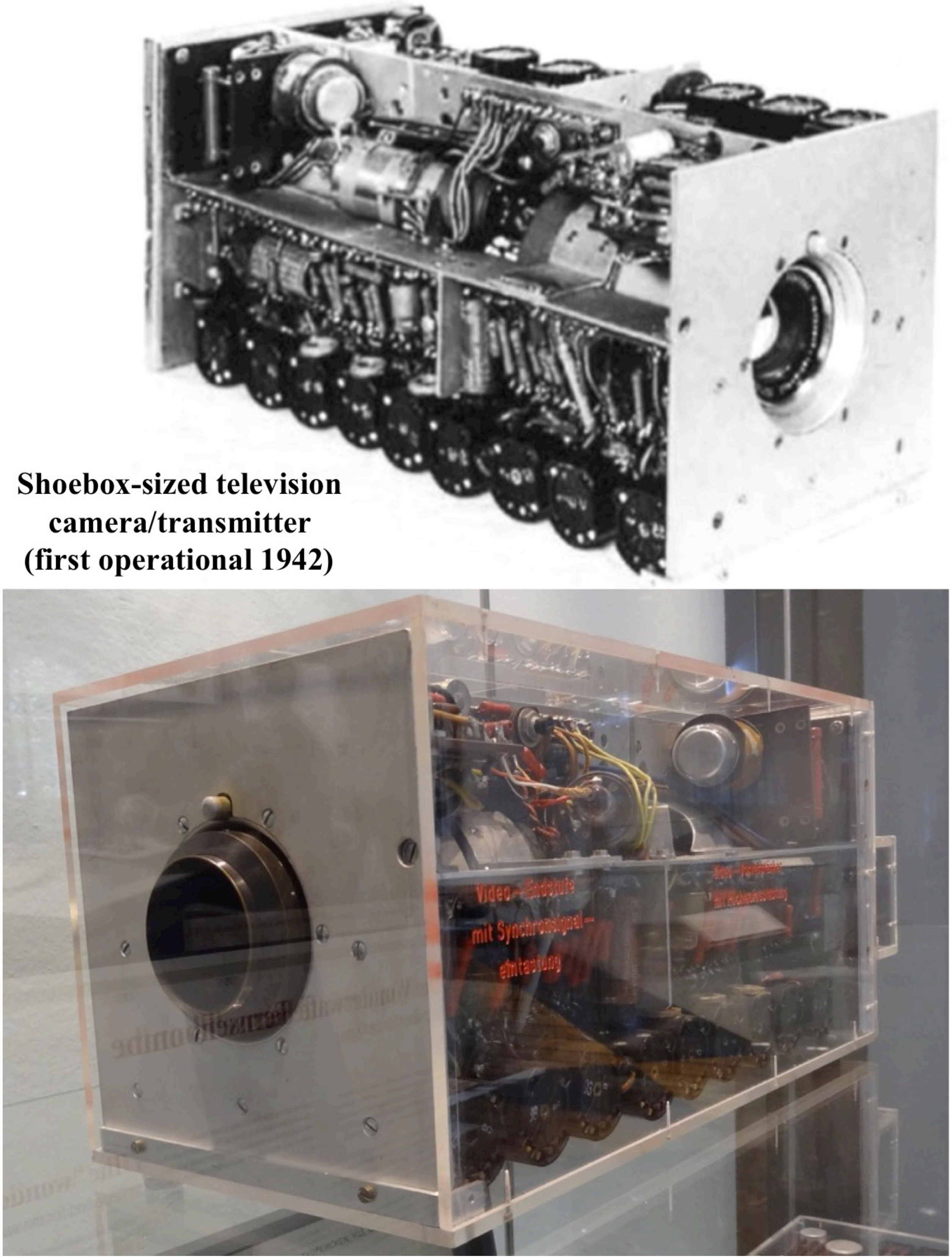


Figure 6.48: German-speaking scientists miniaturized television systems for use in smart bombs and missiles (pp. 1854–1856), as exemplified by this shoebox-sized Tonne television camera/transmitter, which was first operational in 1942. (See also pp. 5482–5487.)

Television camera/transmitter installed in guided missile (first operational 1942)

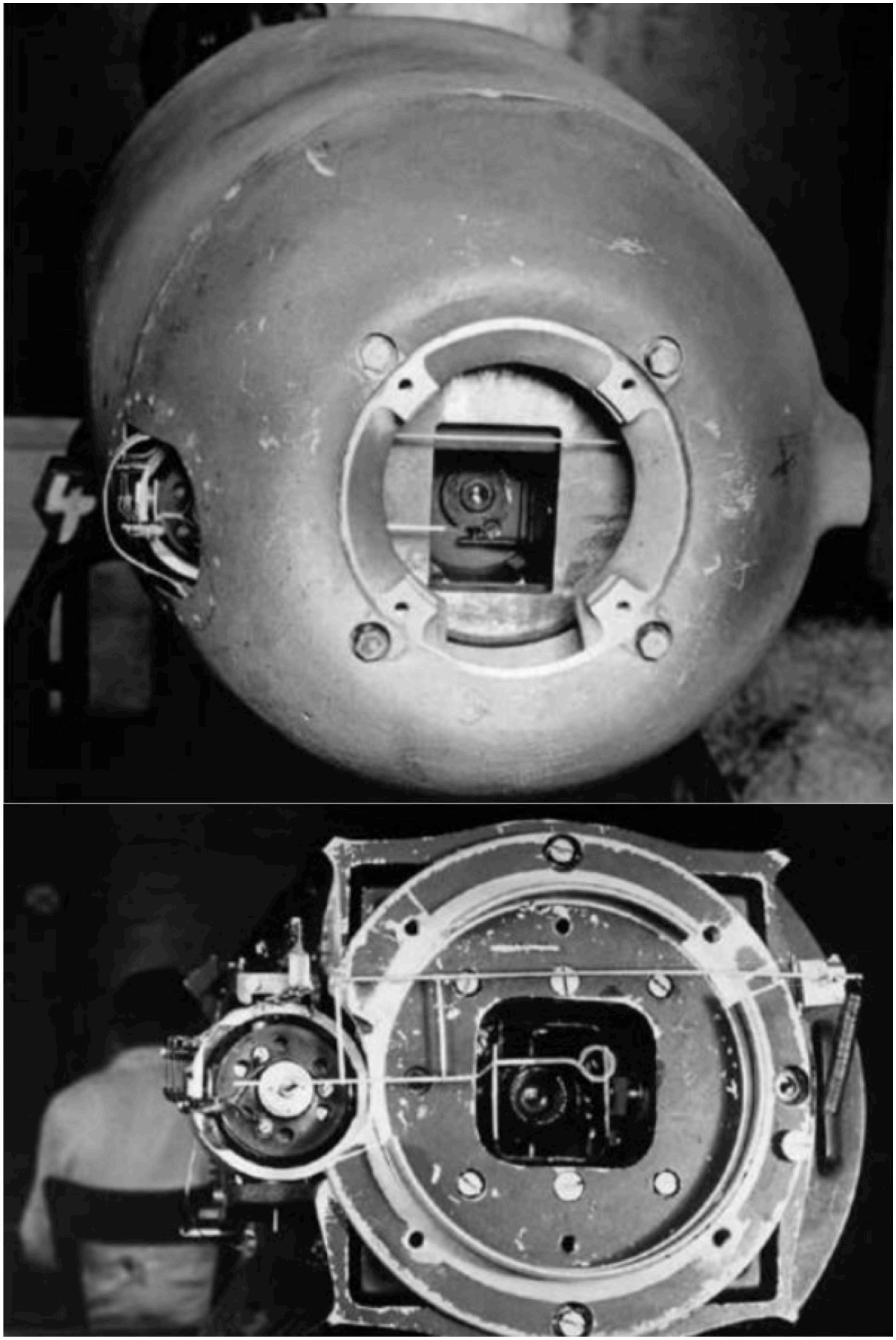


Figure 6.49: German-speaking scientists miniaturized television systems for use in smart bombs and missiles (pp. 1854–1856), as exemplified by this shoebox-sized Tonne television camera/transmitter, which was first operational in 1942. (See also pp. 5482–5487.)

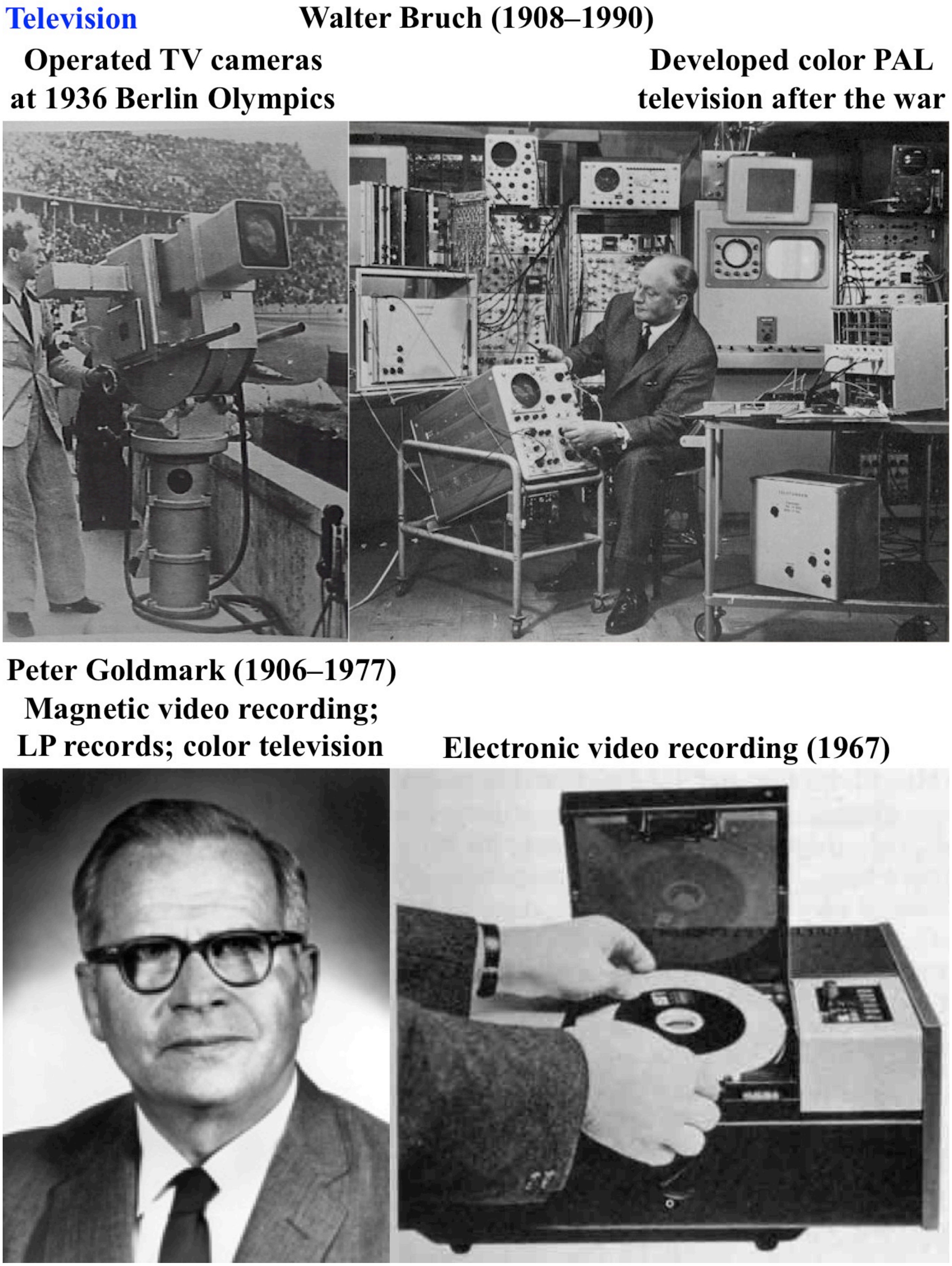


Figure 6.50: Walter Bruch operated TV cameras at the 1936 Berlin Olympics and then developed the color PAL television system after the war. Peter Goldmark developed magnetic video recording (the Electronic Video Recording system, 1967), as well as LP records and a color television system.

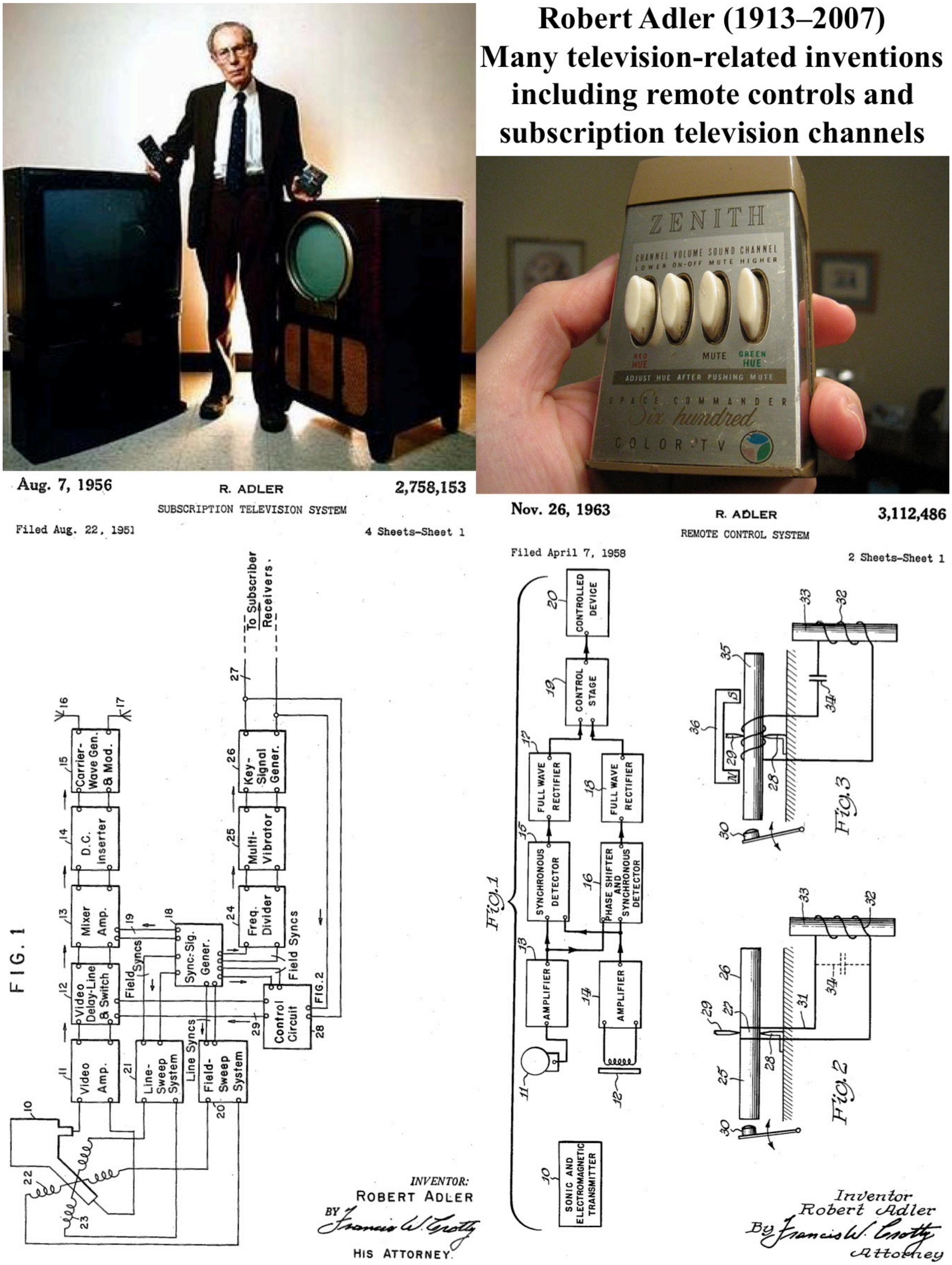


Figure 6.51: Robert Adler made many television-related inventions including remote controls and subscription television channels.

6.3.10 Video Telephone System

Georg Oskar Schubert (German, 1900–1955), working with other engineers at Fernseh and the Reichspost, combined the new television technologies with the already advanced German telephone system, and offered the first public video telephone system beginning in 1936 (Fig. 6.52). The system featured two-way video and audio, a broadband coaxial cable network, and service for customers in cities such as Berlin, Hamburg, Leipzig, Munich, Nuremberg, etc.[7]

During the war, this system was greatly expanded (for example, even including service to underground installations in remote parts of the Reich—see p. 4553) but used only for government business.

Although this system ceased operation in 1945, it was many decades ahead of its time, and the direct forerunner of now-common video teleconferencing calls.

Nearly three decades after the introduction of the German public video telephone system, and after a massive postwar transfer of technologies from Germany (Section B.5), AT&T Bell Laboratories announced it had just then "invented" the "first" public video telephone system [*Look*, 11 August 1964, p. 9]. See Fig. 6.53.

6.3.11 Scanners, Facsimile (Fax) Machines, and Printers

High-speed electronic scanners and facsimile or fax machines were developed in the German-speaking world and transferred to other countries after World War II [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards]. See Figs. 6.54–6.55. Many people were involved in their development, but special mention should go to Arthur Korn (German, 1870–1945) for doing some of the earliest work on this topic, and to Rudolf Hell (German, 1901–2002) for creating fully functional scanners, fax machines, and printers. See also FIAT 908, *The Siemens and Halske Teleprinter, T-Typ 68.*

[7] Gehrts 1940; Gerhart Göbel 1953; Hickethier 1998; *Nature* 1936; von Weiher 1983;
https://www.economist.com/babbage/2010/10/12/telepresence-1936-style
https://vsee.com/blog/a-missing-link-in-the-history-of-the-videophone/
https://web.archive.org/web/20120603145806/http://w3.siemens.de/siemens-stadt/schubrt0.htm

Georg Schubert (1900–1955)

Created and offered the first public video telephone system (Fernseh/Reichspost, 1936–):

- **Two-way video and audio**
- **Broadband coaxial cable network**
- **Serving customers in Berlin, Hamburg, Leipzig, Munich, Nuremberg, etc.**
- **Expanded during the war but used only for government business 1940–1945**

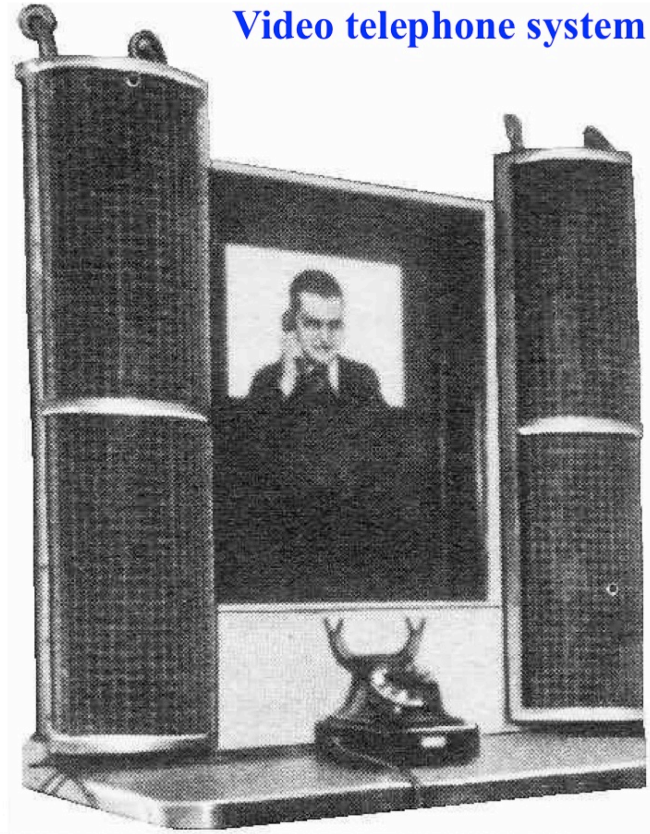
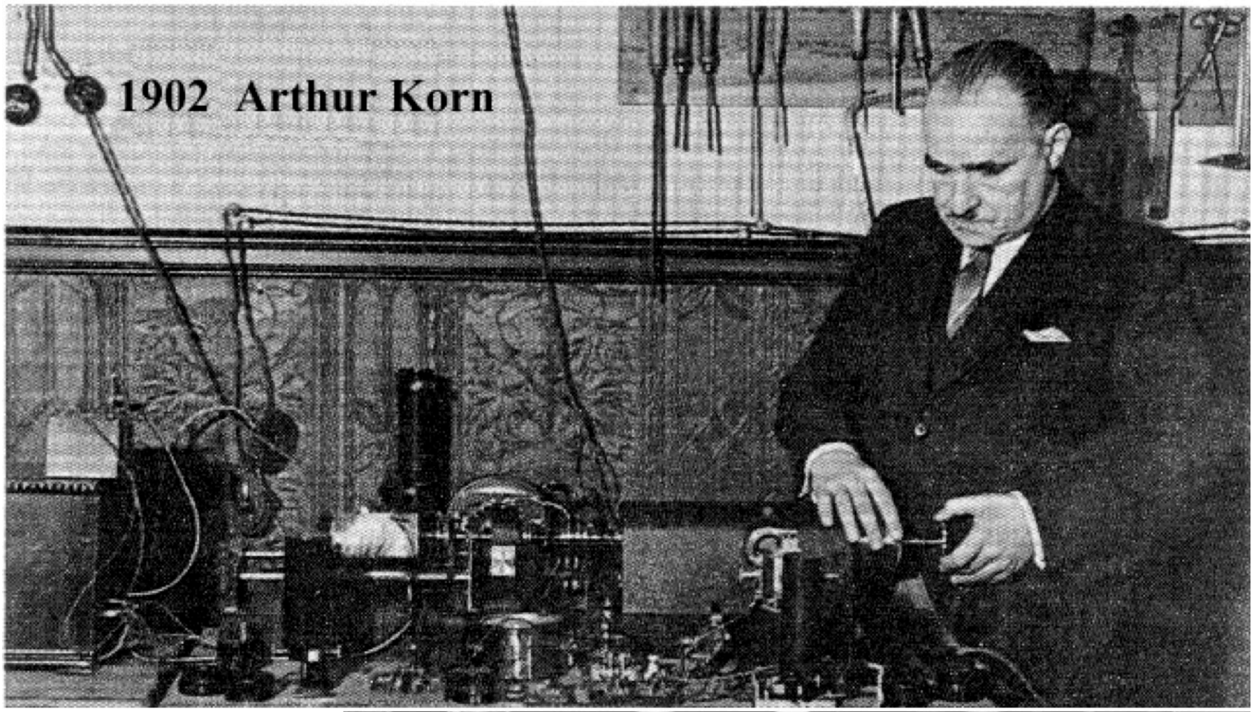


Figure 6.52: Georg Schubert, working with other engineers at Fernseh and the Reichspost, created and offered the first public video telephone system in 1936.

Figure 6.53: Nearly three decades later, and after a massive postwar transfer of technologies from Germany (Section B.5), AT&T Bell Laboratories announced it had just then "invented" the "first" public video telephone system [*Look*, 11 August 1964, p. 9].

Arthur Korn (1870–1945) worked on early scanners and fax machines



Rudolf Hell (in center, 1901–2002)

Scanners, fax machines, and printers

Figure 6.54: High-speed electronic scanners and facsimile or fax machines were developed in the German-speaking world by a series of creators including Arthur Korn and Rudolf Hell (who also developed printers).

NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards

XII

HIGH SPEED FACSIMILE

The discovery of German developments accomplished in the field of Facsimile Communications Systems as a result of wartime research which they conducted for the purpose of meeting high speed communications requirements between airplanes and ground stations will provide American communication companies with information which will be of inestimable value in their efforts to increase the speed of transmission of such communications.

The Germans were seeking a method for transmitting images of messages or pictures very rapidly and in short bursts, as a further means of secret communication. The speed of transmission which the Germans developed was not only considerably faster than that developed thus far domestically but also could be varied. The combination of these factors resulted in the elimination of the possibility of interception of such communications.

By the use of the highest speed developed by the Germans, facsimile communications can be transmitted approximately twenty times faster than that used thus far by domestic communications carriers. Recording of the messages at the receiving station was done photographically and the resolution was of such high quality that only an expert could distinguish between the copy and the original. Such resolution is unobtainable by the American method which employs a dry reproduction process involving the use of a carbon impregnated paper at the receiving station.

All indications are that the exploitation of this development by American communications companies will result in reducing such domestic communication transmission costs if for no other reason than the fact that the circuit use time required for the transmission of such messages can be appreciably reduced.

Information concerning this German development will be made available through the Office of Technical Services of the Department of Commerce.

Figure 6.55: High-speed electronic scanners and facsimile or fax machines were developed in the German-speaking world and transferred to other countries after World War II [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

6.3.12 Photocopiers

Photocopier technology was developed in the German-speaking world and then transferred to other countries during and after the Third Reich. Early forms of the technology used chemically coated, light-sensitive paper. There is some evidence that the modern form of photocopiers, using powdered ink electrostatically attracted to uncoated paper, may have also been developed in wartime Germany, although much more archival research is needed on this topic.

Allied investigators wrote many reports on German photocopier technology after the war. For example, BIOS 1255, *Research in the German Printing Industry*, p. 17, stated:

> The Suitability of Mercury Vapour Lamps for Exposing Pigment Paper for Photogravure: by J. Albrecht and O. Watter.
>
> Comparisons were made on the copying effect of carbon arcs, high-pressure mercury vapour lamps and fluorescent lamps.
>
> At even-distance carbon arcs are superior in using the least energy for equal copying effect but in practice the conditions are varied by the fact that the carbon arc does have a point source combined with high heat-output whereas fluorescent tubes distribute the light emission over a fairly large area with consequent lower heat generation per unit area and permit exposure at much closer distances at the time, giving better light-distribution.
>
> High-pressure mercury vapour lamps are not quite as suited as fluorescent tubes.
>
> Description of a practical arrangement of fluorescent tubes for exposing pigment papers is given.

Among other examples of Allied reports on German photocopier technology, see:

> BIOS 435. *Ozalid Light-Sensitive Materials, Kalle & Co., Wiesbaden—Biebrich (I.G. Farbenindustrie A.G.).* [Ozalid chemical-coated paper for dry photocopying]
>
> BIOS 1475. *Engineers' Sensitised Material and Allied Products.* [Light-sensitive papers for photocopying]
>
> FIAT 528. *German Patents and Patent Applications Concerning Light Sensitive Reproduction Materials and Summary of Patents Issued 1917 Through 1939.* With 62 supplements.
>
> FIAT 813. *Photo-Reproduction Research of Kalle & Co., A.G. Index of Microfilmed Reports.*

As an example that electrostatic rollers for carbon powder were known and used for various applications in wartime Germany, see BIOS 1035, *Metallgesellschaft A.G. and Lurgi Bau, Frankfurt am Main. Electrostatic Separation of Coal and Other Minerals.*

6.3.13 Optical Discs and Digital File Formats

In 1935, Edwin Welte (German, 1876–1958) created a system for recording and playing back music from optical discs, as shown in Fig. 6.56. He patented and produced the system, and continued to improve it through World War II. Much of Welte's work was destroyed in Allied bombing near the end of the war, yet his innovations appear to have exerted direct or indirect influence on postwar work.

The development of lasers (which also originated in the German-speaking world—see Sections 6.4 and C.3) made it much more practical to record and read data on high-density optical discs. The most important postwar laboratory for developing laser optical discs was the Philips Eindhoven research center, which had been closely tied to the rest of the predominantly German-speaking research world from the late nineteenth century through World War II, including work on electronics, communications, and directed energy beams.[8] Various types of laser optical discs (LaserDiscs, compact discs or CDs, digital video discs or DVDs, etc.) were produced from 1969 onward at Philips Eindhoven by Gijs Bouwhuis (Dutch, 19??–), Piet Kramer (Dutch, 19??–), Klaas Compaan (Dutch, 19??–), Kees Schouhamer Immink (Dutch, 1946–), Lou Ottens (Dutch, 1926–), and Joop Sinjou (Dutch, 19??–). See Fig. 6.57. Laser optical disc technology was rapidly adopted by Japan, the United States, and other countries.

Beginning in 1970, Dieter Seitzer (German, 1933–) at the University of Erlangen pioneered methods to compress digital files without a noticeable loss of signal detail. Based on those methods, the now-ubiquitous MP3 digital audio file format was developed and perfected at the Fraunhofer Society by Seitzer's students and associates, including Karlheinz Brandenburg (German, 1954–), Ernst Eberlein (German, 19??–), Heinz Gerhäuser (German, 1946–), Bernhard Grill (German, 1961–), Jürgen Herre (German, 19??–), and Harald Popp (German, 1956–). See Fig. 6.58.

[8] See for example: CIOS III-1; CIOS VI-26, 27; CIOS X-13; CIOS XI-10; CIOS XII-22.

Edwin Welte (1876–1958) created a system for recording and playing back music from optical discs (1935)

№ 712570
KLASSE 51f GRUPPE 1 03
W 97327 IX a/51 f

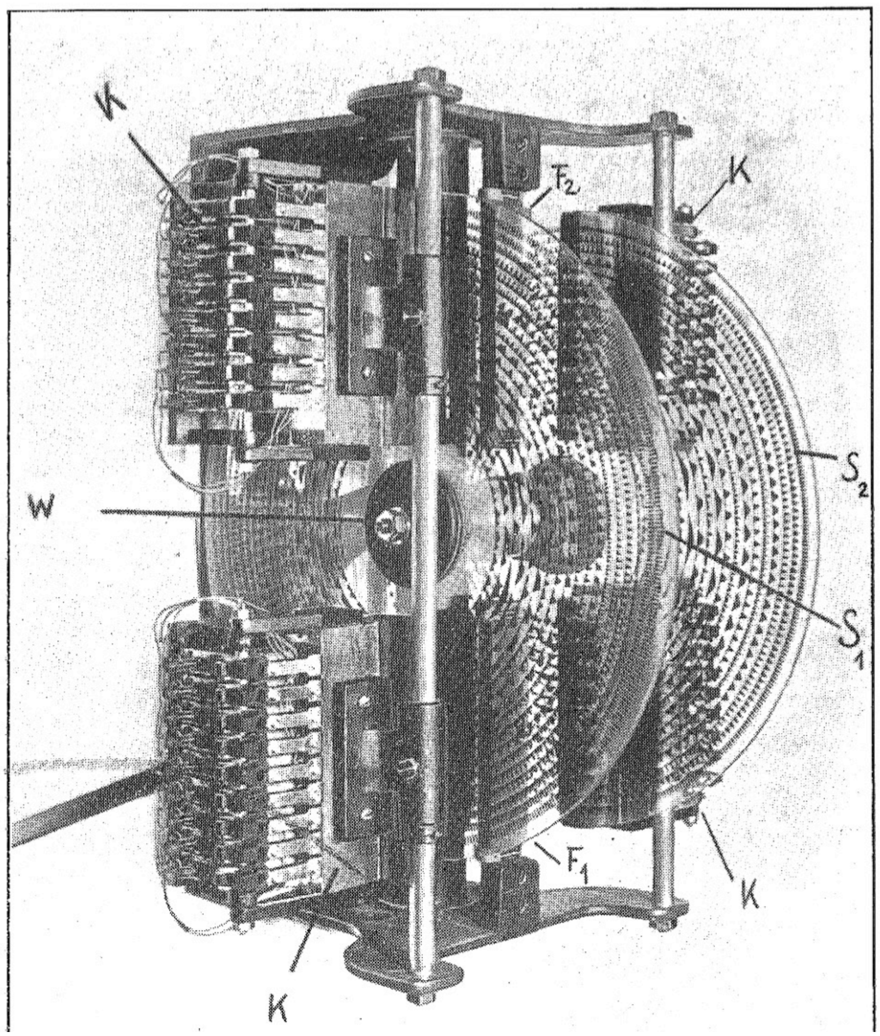
Edwin Welte in Leipzig
Verfahren zum Herstellen von gemischte Stimmen darstellenden Phonogrammen auf Tonscheiben für Lichttonorgeln

Patentiert im Deutschen Reich vom 16. Oktober 1935 an

The main parts of the W.L.O. are electro-optic

TONE-UNITS

with two discs of plate-glass, carrying the sound tracks. They are in detail of construction alike and differ only in regard to the rotating speed of the discs.



W Tone-discs of glass

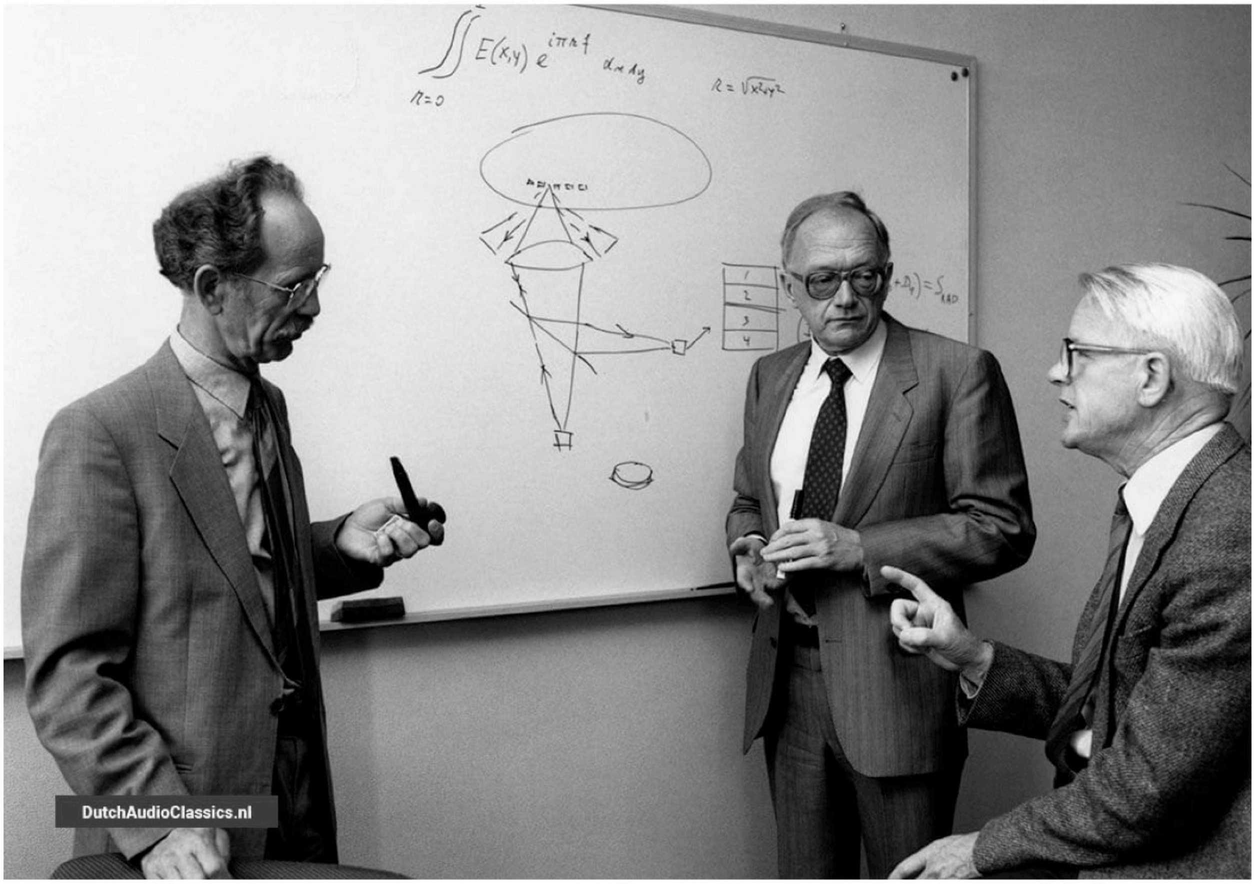
K Elektro-optic relays

F Photocells

S Oscillograms of the single tones

Figure 6.56: In 1935, Edwin Welte created a system for recording and playing back music from optical discs.

Gijs Bouwhuis (19??–) **Laser optical discs (1969 onward)** **Piet Kramer (19??–)** **Klaas Compaan (19??–)**



Kees Schouhamer Immink (1946–) **Lou Ottens (1926–)** **Joop Sinjou (19??–)**

Figure 6.57: Laser optical discs (LaserDiscs, compact discs, digital video discs, etc.) were produced from 1969 onward by Gijs Bouwhuis, Piet Kramer, Klaas Compaan, Kees Schouhamer Immink, Lou Ottens, and Joop Sinjou.

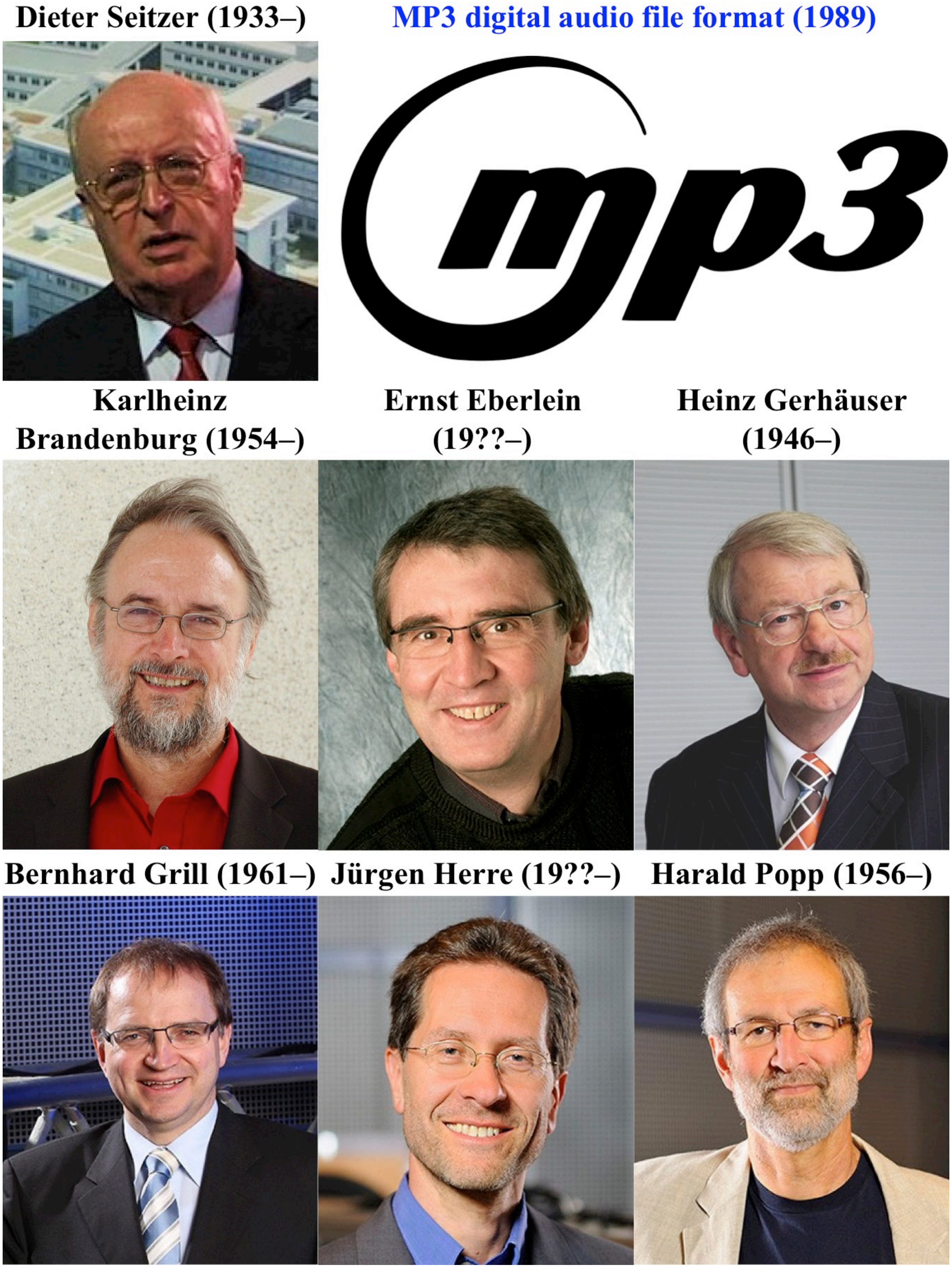


Figure 6.58: The MP3 digital audio file format was developed by Dieter Seitzer, Karlheinz Brandenburg, Ernst Eberlein, Heinz Gerhäuser, Bernhard Grill, Jürgen Herre, and Harald Popp.

6.4 Lasers, Holography, and Laser Spectroscopy

Creators from the greater German-speaking world played key roles in the development of lasers (Section 6.4.1), holography (Section 6.4.2), and laser spectroscopy (Section 6.4.3).

6.4.1 Lasers

A laser (Light Amplification by Stimulated Emission of Radiation) produces light that all has the same wavelength and the same phase, which enables all of the optical power to be concentrated into just one wavelength or color instead of a broader spectrum, and also allows the beam to remain much more tightly focused than a normal beam of light can. (Because the laser light all has the same wavelength and phase unlike a normal light beam, constructive interference with itself keeps it on course, and destructive interference with itself prevents it from veering off course.) According to official histories, the idea of a laser was not proposed until the late 1950s by Charles Townes, Arthur Schawlow, and Gordon Gould, and the first laser was not built until 1960 by Theodore Maiman, all in the United States.[9]

In fact, most of the discoveries and innovations that led to lasers were made decades earlier by German-speaking scientists. Their discoveries prompted the far more publicly visible U.S. work in this field in the late 1950s and early 1960s.

As shown on pp. 1034 and 3120–3122, Albert Einstein (German, 1879–1955) first proposed the idea of stimulated light emission from atoms (amplification of the number of photons of light from atoms) in 1916.

During the period 1919–1926, Christian Füchtbauer (German, 1877–1959), James Franck (German, 1882–1964), Max Born (German, 1882–1970), Walther Bothe (German, 1891–1957), and Hendrik Anthony Kramers (Dutch, 1894–1952) separately wrote several journal articles further developing the theory of stimulated light emission from atoms. See pp. 1035 and 3123–3133.

Putting those theories into experimental practice, Rudolf Ladenburg (1882–1952), Hans Kopfermann (1895–1963), and other members of the Ladenburg group at the Kaiser Wilhelm Institut für Physikalische und Elektrochemie investigated and demonstrated stimulated photon emission from atoms of electrically excited gases during the period 1921–1931. See pp. 1036 and 3133–3145. Because Ladenburg was Jewish and faced rising antisemitism in Germany, he had to discontinue his experiments there and move to the United States. Unfortunately, the U.S. research system at the time had little interest in his work on stimulated photon emission, so his revolutionary progress toward lasers ended.

In 1934, Franz Weidert and Hans Löffler invented neodymium-doped glass with unusual spectral properties that made it suitable for a variety of optical applications, eventually including neodymium glass lasers. See pp. 3146–3150.

[9] See for example: Bertolotti 2015; Bromberg 1991; Hecht 2010; Taylor 2000; Townes 1999.

Ladenburg's research was carried further by Wilhelm von Meyeren (German, 1905–1983). In a 20 February 1945 report to Walther Gerlach, von Meyeren described his 1944 experiments with laser-like monochromatic stimulated light emission from electron population inversions in argon, cesium, or rubidium gases (pp. 1037 and 3155–3174). Von Meyeren appeared to be on the verge of creating an argon laser or other gas laser (or perhaps he succeeded, if he conducted further experiments not mentioned in this one surviving document). However, after the war ended in 1945, von Meyeren's Prague laboratory was ransacked, and von Meyeren was imprisoned for a while and eventually sent empty-handed to West Germany. His hardware and files may well have contributed to the later development of lasers in the Soviet Union.

There is also evidence that there was other major work on lasers in the German-speaking world during the war, and possibly even demonstrations of fully functional prototype lasers (pp. 3175–3197).

For more information on this early developmental work toward lasers, see Section C.3. Much more archival research is needed to investigate the complete history, full accomplishments, and ultimate influence of work in this field by German-speaking scientists.[10]

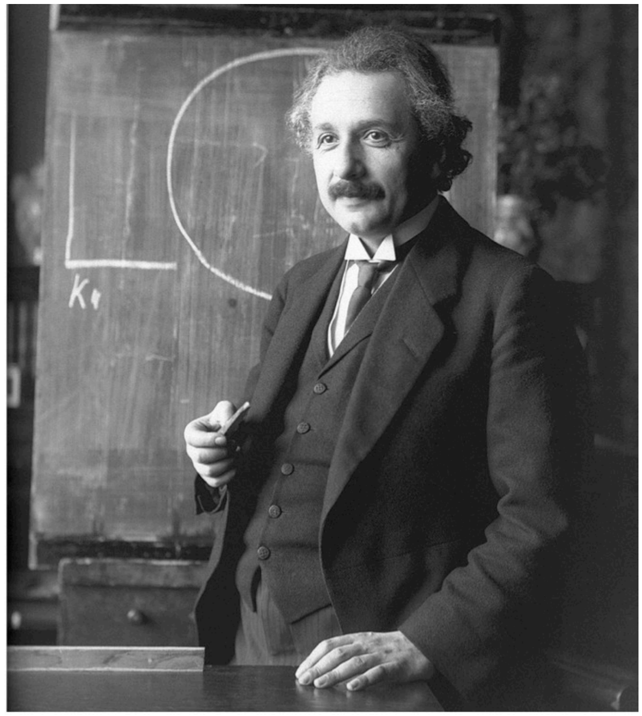
Semiconductor lasers or laser diodes were also created by German-speaking scientists. Laser diodes were designed and developed by John von Neumann (Hungarian, 1903–1957), Walter Heywang (German, 1923–2010), and Herbert Kroemer (German, 1928–). See pp. 1118–1120 and Section B.4.

[10] Albrecht 2019; Bertolotti 2015; Lemmerich 1987.

Lasers (Light Amplification by Stimulated Emission of Radiation)

Albert Einstein (1879–1955)

Theory predicting stimulated emission of photons (1916)



Strahlungs-Emission und -Absorption nach der Quantentheorie;

von A. Einstein.

(Eingegangen am 17. Juli 1916.)

Als Planck vor 16 Jahren die Quantentheorie ins Leben rief, und seine Strahlungsformel aufstellte, schlug er folgenden Weg ein. Er berechnete die mittlere Energie $\overline{E}$ des Resonators in Funktion der Temperatur nach von ihm neu aufgestellten, quantentheoretischen Grundsätzen und bestimmte dann hieraus die Strahlungsdichte ϱ in Funktion der Frequenz ν und der Temperatur, indem er auf elektromagnetischem Wege die Beziehung zwischen Strahlungsdichte und Resonatorenergie $\overline{E}$ aufstellte:

$$\overline{E} = \frac{c^3 \varrho}{8\pi \nu^2}. \qquad 1)$$

Seine Ableitung war von beispielloser Kühnheit, fand aber glänzende Bestätigung. Es bestätigte sich nicht nur die Strahlungsformel selbst und der aus derselben berechnete Wert des Elementarquantums, sondern auch der für $\overline{E}$ quantentheoretisch berechnete Wert durch die späteren Untersuchungen über die spezifische Wärme. Es bestätigte sich somit auch die auf rein elektromagnetischem Wege gewonnene Gleichung 1). Unbefriedigend blieb es aber, daß die elektromagnetisch-mechanische Betrachtung, welche zu 1) führt, mit der Grundidee der Quantentheorie nicht vereinbar ist, und es ist nicht verwunderlich, wenn Planck selbst und alle Theoretiker, die sich mit der Materie befassen, unaufhörlich bemüht sind, die Theorie so umzugestalten, daß sie auf widerpruchsfreien Voraussetzungen beruht.

Seit die Bohrsche Theorie der Spektra ihre großen Erfolge erzielt hat, scheint es nicht zweifelhaft zu sein, daß die Grundidee der Quantentheorie festgehalten werden muß. Es scheint also die Einheitlichkeit der Theorie dadurch hergestellt werden zu müssen, daß die elektromagnetisch-mechanischen Betrachtungen, welche Planck zu der Gleichung 1) führten, durch quantentheoretische Betrachtungen über die Wechselwirkung von

Separat-Abdruck aus:
Mitteilungen der Physikalischen Gesellschaft Zürich - Nr. 18, 1916.

Zur Quantentheorie der Strahlung

von **A. Einstein**.

Die formale Ähnlichkeit der Kurve der chromatischen Verteilung der Temperaturstrahlung mit dem Maxwell'schen Geschwindigkeits-Verteilungsgesetz ist zu frappant, als daß sie lange hätte verborgen bleiben können. In der Tat wurde bereits W. Wien in der wichtigen theoretischen Arbeit, in welcher er sein Verschiebungsgesetz

$$\varrho = \nu^3 f\left(\frac{\nu}{T}\right) \qquad (1)$$

ableitete, durch diese Ähnlichkeit auf eine weitergehende Bestimmung der Strahlungsformel geführt. Er fand hiebei bekanntlich die Formel

$$\varrho = \alpha \nu^3 e^{-\frac{h\nu}{kT}} \qquad (2)$$

welche als Grenzgesetz für große Werte von $\frac{\nu}{T}$ auch heute als richtig anerkannt wird (Wien'sche Strahlungsformel). Heute wissen wir, daß keine Betrachtung, welche auf die klassische Mechanik und Elektrodynamik aufgebaut ist, eine brauchbare Strahlungsformel liefern kann, sondern daß die klassische Theorie notwendig auf die Reileigh'sche Formel

$$\varrho = \frac{k\alpha}{h} \nu^2 T \qquad (3)$$

führt. Als dann Planck in seiner grundlegenden Untersuchung seine Strahlungsformel

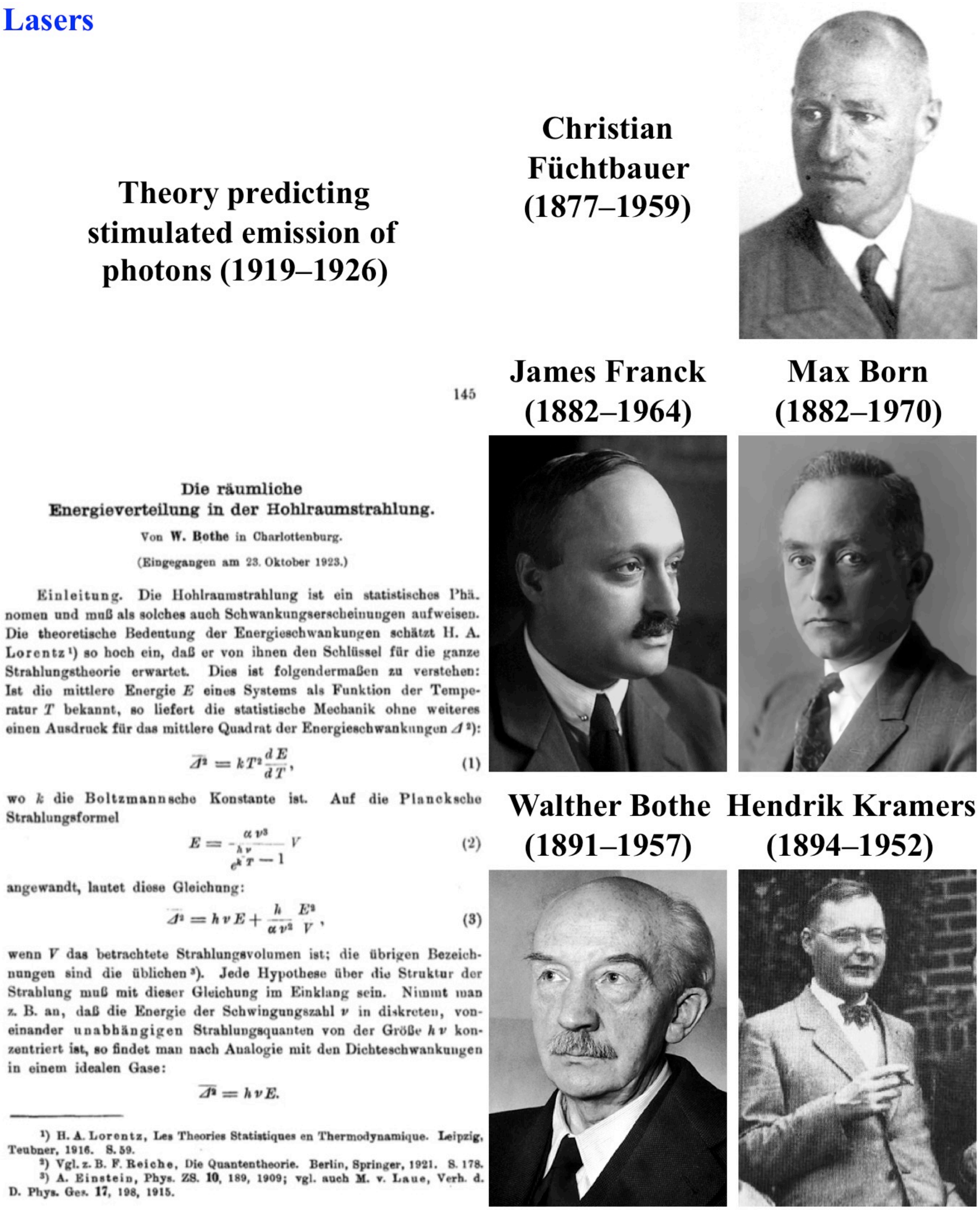
$$\varrho = \alpha \nu^3 \frac{1}{e^{\frac{h\nu}{kT}} - 1} \qquad (4)$$

auf die Voraussetzung von diskreten Energie-Elementen gegründet hatte, aus welcher sich in rascher Folge die Quantentheorie entwickelte, geriet jene Wien'sche Überlegung, welche zur Gleichung (2) geführt hatte, naturgemäß wieder in Vergessenheit.

Vor kurzem nun fand ich eine der ursprünglichen Wien'schen Betrachtung [1]) verwandte, auf die Grundvoraussetzung der Quanten-

Figure 6.59: Albert Einstein first proposed the idea of stimulated light emission from atoms (amplification of the number of photons of light from atoms) in 1916.

Lasers



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Die räumliche Energieverteilung in der Hohlraumstrahlung.

Von **W. Bothe** in Charlottenburg.

(Eingegangen am 23. Oktober 1923.)

Einleitung. Die Hohlraumstrahlung ist ein statistisches Phänomen und muß als solches auch Schwankungserscheinungen aufweisen. Die theoretische Bedeutung der Energieschwankungen schätzt H. A. Lorentz [1]) so hoch ein, daß er von ihnen den Schlüssel für die ganze Strahlungstheorie erwartet. Dies ist folgendermaßen zu verstehen: Ist die mittlere Energie E eines Systems als Funktion der Temperatur T bekannt, so liefert die statistische Mechanik ohne weiteres einen Ausdruck für das mittlere Quadrat der Energieschwankungen Δ^2 [2]):

$$\overline{\Delta^2} = kT^2 \frac{dE}{dT}, \tag{1}$$

wo k die Boltzmannsche Konstante ist. Auf die Plancksche Strahlungsformel

$$E = \frac{\alpha \nu^3}{e^{\frac{h\nu}{kT}} - 1} V \tag{2}$$

angewandt, lautet diese Gleichung:

$$\overline{\Delta^2} = h\nu E + \frac{h}{\alpha \nu^2} \frac{E^2}{V}, \tag{3}$$

wenn V das betrachtete Strahlungsvolumen ist; die übrigen Bezeichnungen sind die üblichen [3]). Jede Hypothese über die Struktur der Strahlung muß mit dieser Gleichung im Einklang sein. Nimmt man z. B. an, daß die Energie der Schwingungszahl ν in diskreten, voneinander unabhängigen Strahlungsquanten von der Größe $h\nu$ konzentriert ist, so findet man nach Analogie mit den Dichteschwankungen in einem idealen Gase:

$$\overline{\Delta^2} = h\nu E.$$

[1]) H. A. Lorentz, Les Theories Statistiques en Thermodynamique. Leipzig, Teubner, 1916. S. 59.
[2]) Vgl. z. B. F. Reiche, Die Quantentheorie. Berlin, Springer, 1921. S. 178.
[3]) A. Einstein, Phys. ZS. **10**, 189, 1909; vgl. auch M. v. Laue, Verh. d. D. Phys. Ges. **17**, 198, 1915.

Figure 6.60: Christian Füchtbauer, James Franck, Max Born, Walther Bothe, and Hendrik Anthony Kramers further developed the theory of stimulated light emission from atoms (amplification of the number of photons of light from atoms) during the period 1919–1926.

Lasers

Experiments with stimulated emission of photons (1921–1931)

Rudolf Ladenburg (1882–1952)

Hans Kopfermann (1895–1963)

(Mitteilung aus dem Kaiser Wilhelm-Institut für physikalische und Elektrochemie.)

Untersuchungen über die anomale Dispersion angeregter Gase.

V. Teil*.

Negative Dispersion in angeregtem Neon.**

Von **H. Kopfermann** und **R. Ladenburg** in Berlin-Dahlem.

Mit 6 Abbildungen. (Eingegangen am 12. August 1930.)

Bei Steigerung der Stromdichte in der positiven Säule einer Neon-Entladung findet man zunächst ein Ansteigen der anomalen Dispersion an den rotgelben *s*-*p*-Linien, gemessen durch die Werte $\mathfrak{N}$, und zwar verhalten sich alle zum gleichen unteren *s*-Zustand gehörigen Linien in gleicher Weise — dies entspricht dem Ansteigen der Atomdichten im *s*-Zustand N_s. Vermehrt man aber die Stromdichte über $\sim 0{,}1$ Amp./qcm (bei 1 mm Neondruck), so nehmen die $\mathfrak{N}$-Werte wieder langsam ab, und zwar für die verschiedenen Linien $s_5 - p_{10}$, p_9, p_8 . . . bis p_2 in merklich verschiedener Weise (Fig. 4 und 5). Dies ist durch das allmähliche und verschieden starke Anwachsen der Atomdichten in den *p*-Zuständen, $N_{p_{10}}$, N_{p_9} ... zu deuten und durch die dadurch hervorgerufene „negative Dispersion" gemäß der Formel

$$\mathfrak{N}_{s_5 p_k} = N_{s_5} f_{s_5 p_k} \left(1 - \frac{N_{p_k}}{N_{s_5}} \frac{g_{s_5}}{g_{p_k}}\right).$$

Diese Deutung wird durch Untersuchung der „Umkehr" der Neonlinien bestätigt, die ein ähnliches Anwachsen des Verhältnisses $V = N_{p_k}/N_{s_5} \cdot g_{s_5}/g_{p_k}$ zeigt. Aus den Messungen läßt sich unter gewissen theoretisch näher begründeten Annahmen über die Stromabhängigkeit der Atomdichte im s_5-Zustand das Verhältnis V und der Anstieg der N_{p_k}-Werte mit dem Strom berechnen (Fig. 6). Bei dem größten bisher erreichten Strom von 700 mA in einem 0,8 cm weiten Rohr nähern sich die N_p-Werte einem „Sättigungswert", es scheint sich ein statistisches Gleichgewicht zwischen den Atomdichten in den verschiedenen Zuständen und den anregenden und vernichtenden Elektronen auszubilden. Definiert man die zu den *s*- und *p*-Zuständen gehörige spezifische Temperatur Θ durch die Formel

$$\ln V_{ps} = -\frac{E_p - E_s}{k\ \Theta_{sp}} = -\frac{h\,c}{k\ \lambda_{sp}} \frac{1}{\Theta_{sp}},$$

* Teil I, II, III und IV der U. a. D. siehe ZS. f. Phys. **48**, 15, 26, 51 u. 192, 1928. Sie werden hier als U. a. D. I . . . IV zitiert.

** Ein Teil der in vorliegender Mitteilung dargestellten Versuche und Überlegungen wurde bereits in dem Haber-Band der ZS. f. phys. Chem. (A) 375, 1928 veröffentlicht.

Experimenteller Nachweis der „negativen" Dispersion [1].

Von

H. Kopfermann und R. Ladenburg.

(Aus dem Kaiser Wilhelm-Institut für physikalische Chemie und Elektrochemie, Berlin-Dahlem.)

(Mit 5 Figuren im Text.)

(Eingegangen am 12. 9. 28.)

Bei wachsender Stromdichte in der positiven Säule einer Neonentladung bis etwa 0·1 Amp. pro Quadratzentimeter findet man ein Ansteigen der anomalen Dispersion an den gelbroten $s - p$-Linien (p ist der höhere, energiereichere, s der tiefere, energieärmere Zustand). Das bedeutet ein ebensolches Anwachsen der angeregten Atome in den *s*-Zuständen. Steigert man aber die Stromdichte weiterhin, so beobachtet man nunmehr eine allmähliche Abnahme des Betrages der anomalen Dispersion (der $\mathfrak{N}$-Werte) an den verschiedenen $s_5 - p_k$-Linien ($k = 10, 9, 8, 6, 4, 2$) mit steigendem Strom, gerade, wie die quantentheoretische Dispersionsformel wegen des Einflusses der „negativen" Dispersion, nämlich infolge stärkerer Anregung der Atome in den p_k-Zuständen erwarten lässt. Kontrollversuche schliessen andere Deutungen der Versuchsergebnisse aus, vor allem wegen der systematisch verschiedenen Abnahme der $\mathfrak{N}$-Werte der mit verschiedenen p_k-Niveaus kombinierenden s_5-Linien: Je tiefer nämlich das betreffende *p*-Niveau liegt, und je stärker es angeregt wird, um so grösser ist die Abnahme der zugehörigen anomalen Dispersion.

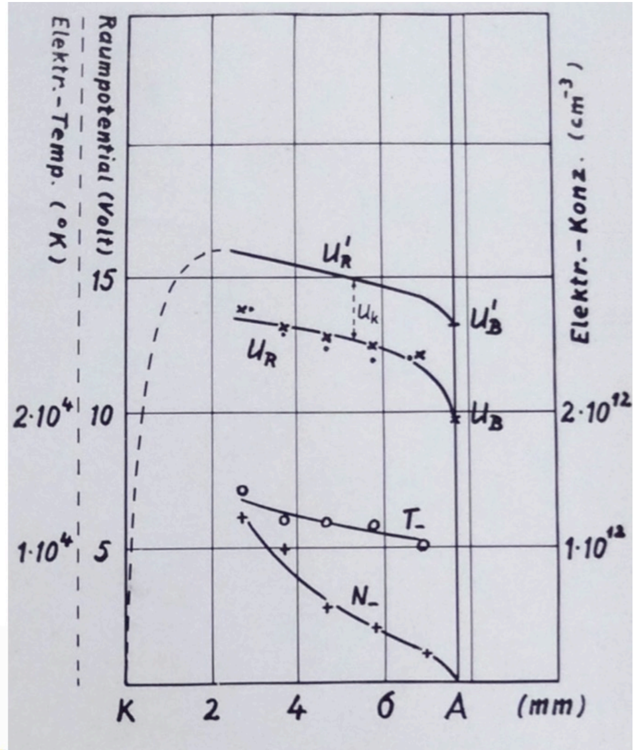
1. Die Theorie des Strahlungsgleichgewichts im Hohlraum und die Ableitung der Planckschen Strahlungsformel erfordern neben der Berücksichtigung der gewöhnlichen Absorptionsprozesse die Annahme einer „negativen Absorption". Je nach dem Schwingungszustand, in dem ein Oszillator von der auffallenden Strahlung getroffen wird, kann er ihr Energie entziehen oder hinzufügen. In der Bohr-Einsteinschen Auffassung tritt an Stelle des Oszillators ein Atom, das unter der Einwirkung auffallender Strahlung aus einem tieferen Quantenzustand j in einen höheren Zustand k unter Absorption von Strahlungsenergie gehoben — oder aus dem höheren Zustand in den tieferen unter Emission von Strahlung der gleichen Frequenz ν_{kj} zurückgebracht wird. Diese Prozesse „erzwungener Emission" addieren sich im Strahlungsgleichgewicht zu den Prozessen „spontaner Emis-

[1]) Vorgetragen auf dem 6. russischen Physikerkongress in Moskau am 6. August 1928.

Figure 6.61: Rudolf Ladenburg, Hans Kopfermann, and other members of the Ladenburg group at the Kaiser Wilhelm Institut für Physikalische und Elektrochemie investigated and demonstrated stimulated light emission from atoms (amplification of the number of photons of light from atoms) during the period 1921–1931.

Lasers

Wilhelm von Meyeren (1905–1983)



Experiments with stimulated emission of photons (1944)

NARA RG 319, Entry NM3-82A, Box 6, Folder G3

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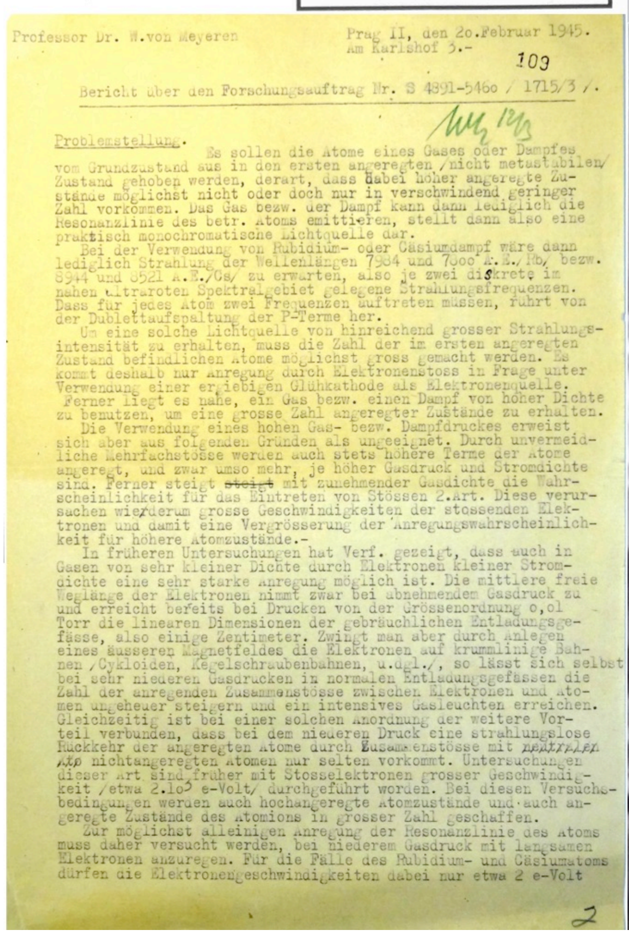

Professor Dr. W.von Meyeren

Prag II, den 2o.Februar 1945.
Am Karlshof 3.-

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Bericht über den Forschungsauftrag Nr. S 4891-546o / 1715/3 /.

Problemstellung. Es sollen die Atome eines Gases oder Dampfes vom Grundzustand aus in den ersten angeregten /nicht metastabilen/ Zustand gehoben werden, derart, dass dabei höher angeregte Zustände möglichst nicht oder doch nur in verschwindend geringer Zahl vorkommen. Das Gas bezw. der Dampf kann dann lediglich die Resonanzlinie des betr. Atoms emittieren, stellt dann also eine praktisch monochromatische Lichtquelle dar.

Bei der Verwendung von Rubidium- oder Cäsiumdampf wäre dann lediglich Strahlung der Wellenlängen 7984 und 78oo A.E./Rb/ bezw. 8944 und 8521 A.E./Cs/ zu erwarten, also je zwei diskrete im nahen ultraroten Spektralgebiet gelegene Strahlungsfrequenzen. Dass für jedes Atom zwei Frequenzen auftreten müssen, rührt von der Dublettaufspaltung der P-Terme her.

Um eine solche Lichtquelle von hinreichend grosser Strahlungsintensität zu erhalten, muss die Zahl der im ersten angeregten Zustand befindlichen Atome möglichst gross gemacht werden. Es kommt deshalb nur Anregung durch Elektronenstoss in Frage unter Verwendung einer ergiebigen Glühkathode als Elektronenquelle.

Ferner liegt es nahe, ein Gas bezw. einen Dampf von hoher Dichte zu benutzen, um eine grosse Zahl angeregter Zustände zu erhalten.

Die Verwendung eines hohen Gas- bezw. Dampfdruckes erweist sich aber aus folgenden Gründen als ungeeignet. Durch unvermeidliche Mehrfachstösse werden auch stets höhere Terme der Atome angeregt, und zwar umso mehr, je höher Gasdruck und Stromdichte sind. Ferner steigt ~~steigt~~ mit zunehmender Gasdichte die Wahrscheinlichkeit für das Eintreten von Stössen 2.Art. Diese verursachen wiederum grosse Geschwindigkeiten der stossenden Elektronen und damit eine Vergrösserung der Anregungswahrscheinlichkeit für höhere Atomzustände.-

In früheren Untersuchungen hat Verf. gezeigt, dass auch in Gasen von sehr kleiner Dichte durch Elektronen kleiner Stromdichte eine sehr starke Anregung möglich ist. Die mittlere freie Weglänge der Elektronen nimmt zwar bei abnehmendem Gasdruck zu und erreicht bereits bei Drucken von der Grössenordnung o,ol Torr die linearen Dimensionen der gebräuchlichen Entladungsgefässe, also einige Zentimeter. Zwingt man aber durch Anlegen eines äusseren Magnetfeldes die Elektronen auf krummlinige Bahnen /Cykloiden, Kegelschraubenbahnen, u.dgl./, so lässt sich selbst bei sehr niederen Gasdrucken in normalen Entladungsgefässen die Zahl der anregenden Zusammenstösse zwischen Elektronen und Atomen ungeheuer steigern und ein intensives Gasleuchten erreichen. Gleichzeitig ist bei einer solchen Anordnung der weitere Vorteil verbunden, dass bei dem niederen Druck eine strahlungslose Rückkehr der angeregten Atome durch Zusammenstösse mit ~~neutralen Ato~~ nichtangeregten Atomen nur selten vorkommt. Untersuchungen dieser Art sind früher mit Stosselektronen grosser Geschwindigkeit /etwa 2.1o³ e-Volt/ durchgeführt worden. Bei diesen Versuchsbedingungen werden auch hochangeregte Atomzustände und auch angeregte Zustände des Atomions in grosser Zahl geschaffen.

Zur möglichst alleinigen Anregung der Resonanzlinie des Atoms muss daher versucht werden, bei niederem Gasdruck mit langsamen Elektronen anzuregen. Für die Fälle des Rubidium- und Cäsiumatoms dürfen die Elektronengeschwindigkeiten dabei nur etwa 2 e-Volt

2

Figure 6.62: In a 20 February 1945 report to Walther Gerlach, Wilhelm von Meyeren described his 1944 experiments with laser-like monochromatic stimulated light emission from electron population inversions in argon, cesium, or rubidium gases.

6.4.2 Holography

Ludwig Mach (Austrian, 1868–1951) and Ludwig Zehnder (Swiss, 1854–1949) developed the Mach-Zehnder interferometer during the period 1891–1892. A Mach-Zehnder interferometer splits a collimated and preferably monochromatic beam of light into two beams, passes one beam through a transparent object (or reflected off a non-transparent object), then recombines the beams, which are projected onto a screen. Phase changes to the light waves caused by the object create constructive and destructive interference and thus visible patterns that can provide useful information about the object. See Fig. 6.63.

Ludwig Mach was the son of Ernst Mach (Austrian, 1838–1916). Ludwig and Ernst Mach used similar principles to visualize shock waves around bullets traveling faster than the speed of sound through air (p. 1669).

The Mach-Zehnder interferometric approach was later applied to microscopes, resulting in phase contrast microscopy (p. 1283).

In 1947, Dennis Gabor (Hungarian but educated and worked in Germany, 1900–1979) invented holography by applying Mach-Zehnder interferometry to photography (Fig. 6.64). Essentially, a holographic recording system is a Mach-Zehnder interferometer used as a camera, with photographic film placed at the final point to record the constructive and destructive interference produced when half of the light beam encounters an object and then the two halves of the beam are recombined. Such an image appears three-dimensional to human eyes, unlike regular photographs. (Though invented in 1947, holography later became a more powerful and more practical technique once lasers were readily available to be used as the light source.)

For introducing and developing holography, Gabor won the Nobel Prize in Physics in 1971. Professor Erik Ingelstam of the Royal Academy of Sciences discussed the far-reaching applications of Gabor's methods [https://www.nobelprize.org/prizes/physics/1971/ceremony-speech/]:

> [...I]mportant information about the object is missing in a photographic image. This is a problem which has been a key one for Dennis Gabor during his work on information theory. Because the image reproduces only the effect of the intensity of the incident wave-field, not its nature. The other characteristic quantity of the waves, phase, is lost and thereby the three dimensional geometry. The phase depends upon from which direction the wave is coming and how far it has travelled from the object to be imaged.
>
> Gabor found the solution to the problem of how one can retain a wave-field with its phase on a photographic plate. A part of the wave-field, upon which the object has not had an effect, namely a reference wave, is allowed to fall on the plate together with the wave-field from the object. These two fields are superimposed upon one another, they interfere, and give the strongest illumination where they have the same phase, the weakest where they extinguish each other by having the opposite phase. Gabor called this plate a hologram, from the Greek holos, which means whole or complete, since the plate contains the whole information. This information is stored in the plate in a coded form. When the hologram is irradiated only with the reference wave, this wave is deflected in the hologram structure, and the original object's field is reconstructed.

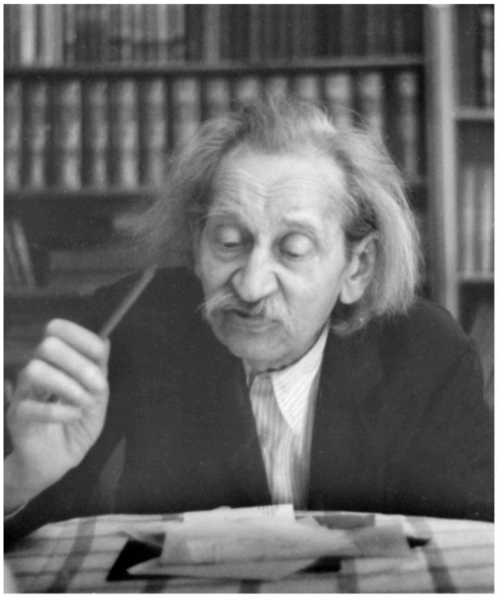
The result is a three dimensional image.

Gabor originally thought of using the principle to make an electron microscope image in two steps: first to register an object's field with electron rays in a hologram, and then to reconstruct this with visible light to make a three dimensional image with high resolution. But suitable electron sources for this were not available, and also for other technical reasons the idea could not be tested. However, through successful experiments with light Gabor could show that the principle was correct. In three papers from 1948 to 1951 he attained an exact analysis of the method, and his equations, even today, contain all the necessary information. [...]

The fascinated observer's admiration when he experiences the three dimensional space effect in a holographic image is, however, an unsufficient acknowledgement for the inventor. More important are the scientific and technical uses to which his idea has led. The position of each object's point in space is determined to a fraction of a light wave-length, a few ten-thousandths of a millimetre, thanks to the phase in the wave-field. With this, the hologram has, in an unexpected way, enriched optical measurement techniques, and particularly interferometric measurements have been made possible on many objects. The shape of the object at different times can be stored in one and the same hologram, through illumination of it several times. When they are reconstructed simultaneously, the different wave-fields interfere with each other, and the image of the object is covered with interference lines, which directly, in light wavelengths, correspond to changes of shape between the exposures. These changes can also be, for example, vibrations in a membrane or a musical instrument.

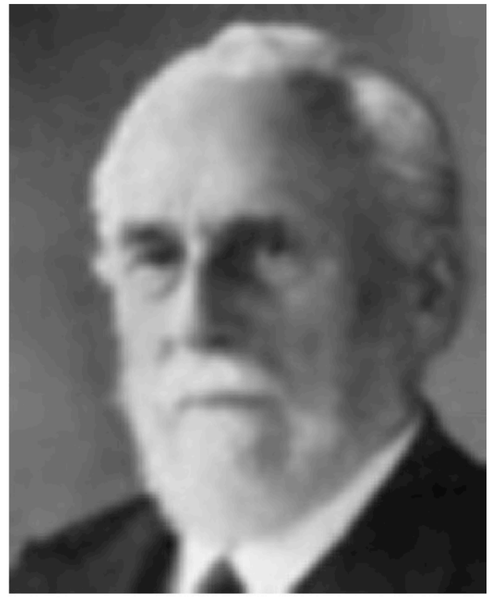
Also, very rapid sequences of events, even in plasma physics, are amenable to analysis through hologram exposures at certain times with short light flashes from modern impulse lasers.

Gabor's original thought to use different waves for both steps within holography, has been taken up in many connections. It is especially attractive to use ultra sound waves for exposures, so that, in the second step, a sound field is reconstructed in the shape of an optical image. Despite significant difficulties there is work, with a certain amount of progress, being done in this area. Such a method should be of value for medical diagnosis, since the deflected sound field gives different information from that in X ray radiography.



Ludwig Mach (1868–1951)

Ludwig Zehnder (1854–1949)



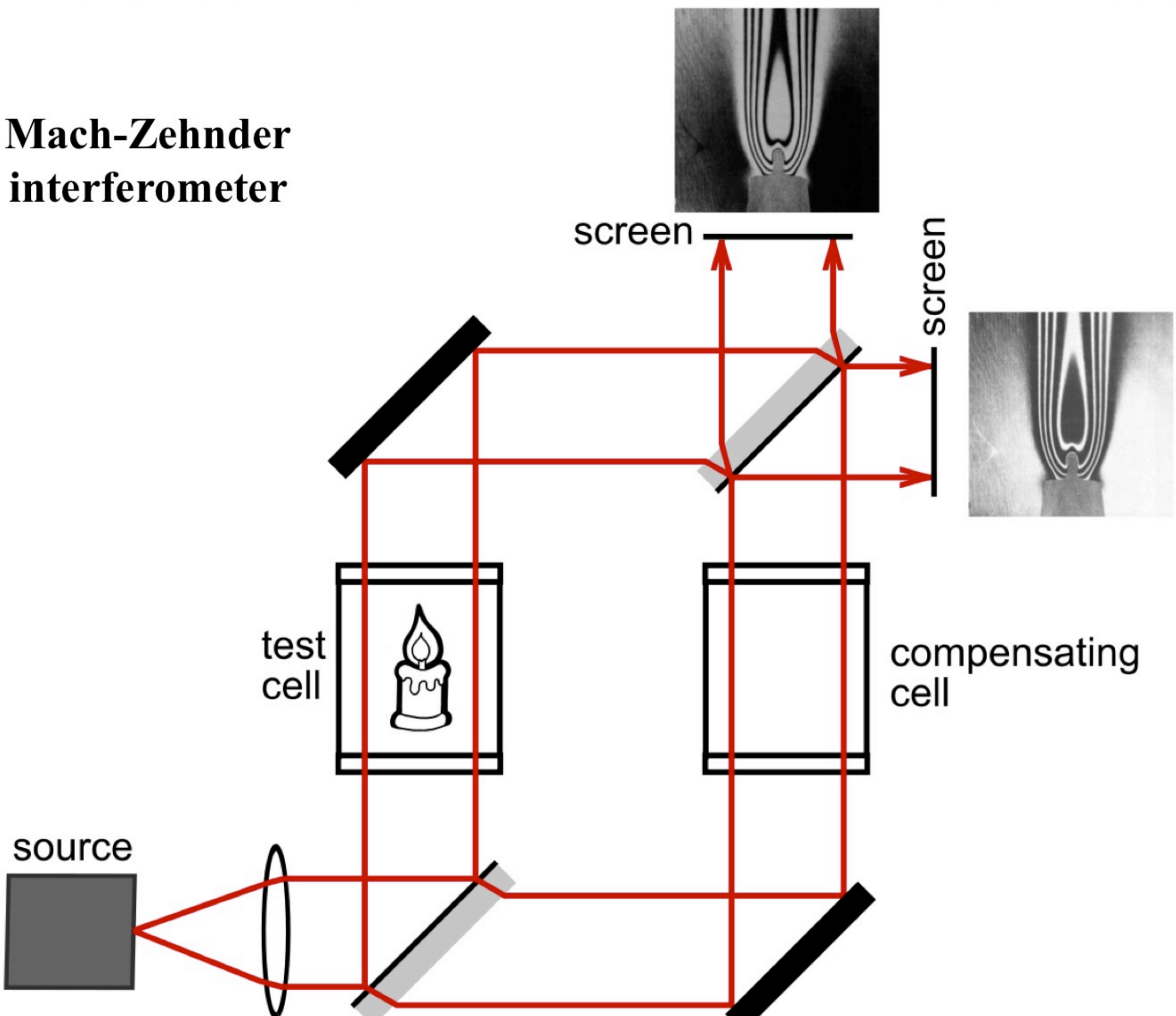


Figure 6.63: Ludwig Mach and Ludwig Zehnder developed the Mach-Zehnder interferometer during the period 1891–1892.

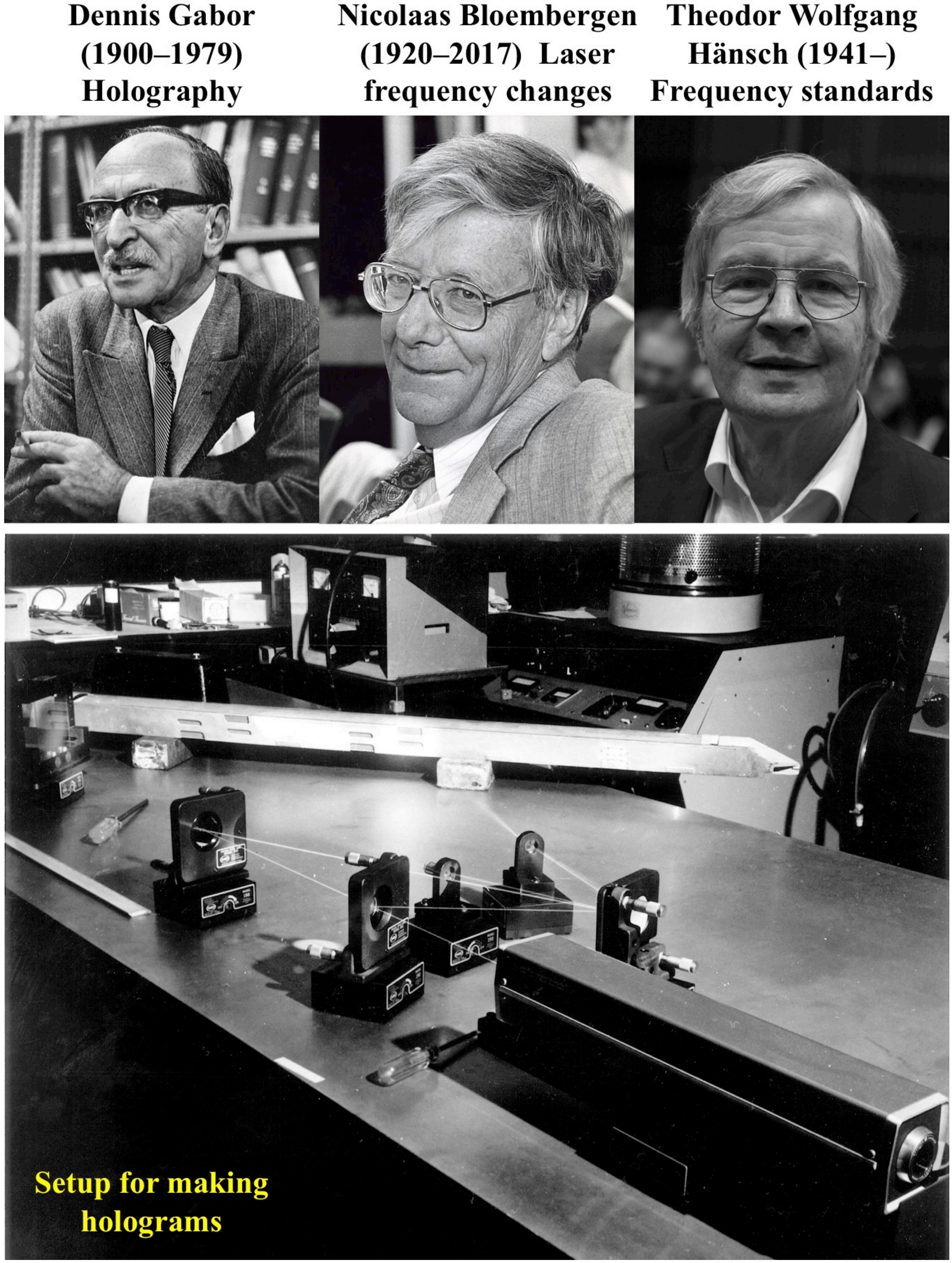


Figure 6.64: Dennis Gabor invented holography (essentially using a Mach-Zehnder interferometer as a camera), Nicolaas Bloembergen used nonlinear optics to increase or decrease laser frequencies by multiples, and Theodor Wolfgang Hänsch developed more precise laser frequency standards.

6.4.3 Laser Spectroscopy

Nicolaas Bloembergen (Dutch, 1920–2017, Fig. 6.64) developed early magnetic resonance imaging (MRI) machines and invented methods of using nonlinear optics to convert laser beams of one frequency or wavelength into beams of other frequencies or wavelengths (for example by halving or by doubling the frequency). He won the Nobel Prize in Physics in 1981 for his laser work. Professor Ingvar Lindgren of the Royal Swedish Academy of Sciences described that research and its applications [https://www.nobelprize.org/prizes/physics/1981/ceremony-speech/]:

> Nicolaas Bloembergen has contributed to the development of laser spectroscopy in a different way. Laser light is sometimes so intense that, when it is shone on to matter, the response of the system could not be described by existing theories. Bloembergen and his collaborators have formulated a more general theory to describe these effects and founded a new field of science we now call non-linear optics. Several laser spectroscopy methods are based upon this phenomenon, particularly such methods where two or more beams of laser light are mixed in order to produce laser light of a different wave length. Such methods can be applied in many fields, for instance, for studying combustion processes. Furthermore, it has been possible in this way to generate laser light of shorter as well as longer wave lengths, which has extended the field of application for laser spectroscopy quite appreciably.

Theodor Wolfgang Hänsch (German, 1941–, Fig. 6.64) developed more precise laser frequency standards, for which he won the Nobel Prize in Physics in 2005 (along with John Hall). Professor Stig Stenholm, a member of the Royal Swedish Academy of Sciences, explained the importance of the innovation [https://www.nobelprize.org/prizes/physics/2005/ceremony-speech/]:

> John Hall and Theodor Hänsch have worked on ever-improved standard references for frequency measurements. In order to compare an unknown period of light with the reference, they have developed the frequency comb technique. This gives a sequence of exactly separated frequencies and a method to set this measuring rod against an unknown frequency. Thus one obtains an extremely accurate number for the unknown period. This allows spectroscopic measurements with extremely high precision. Today this technique is as exact as the methods developed for this purpose during earlier decades, but it promises many times improved accuracy.
>
> The history of physics shows that, when the accuracy of measurements is improved, new physics may be discovered and explored. The work honored today facilitates tests of our basic theories in physics. The character of time and space may be clarified, and the limitations of the laws of physics may be established.

6.5 Solid State Physics and Microelectronics

German-speaking creators made many of the revolutionary advances in solid state physics and microelectronics that have made the modern world possible, yet to date, the full extent of their contributions has not been widely understood and recognized.[11]

This section gives an overview of the critical roles played by creators from the German-speaking world with regard to:

6.5.1. Solid state physics

6.5.2. Semiconductor materials and devices

6.5.3. Transistors

6.5.4. Postwar transfer of microelectronics technologies

6.5.5. Capacitors

6.5.6. Printed circuits

6.5.7. Integrated circuits

6.5.8. Light emitting diodes and laser diodes

6.5.9. Superconductivity

6.5.10. Piezoelectricity

For more extensive documentation in these areas, see Appendix B.

6.5.1 Solid State Physics

Solid state physics, the basic science underlying microelectronics, describes the motions of negatively charged electrons and positively charged ions in crystal lattices. Figure 6.65 gives a simple visual explanation of some of the major aspects of solid state physics.

[11]For individual pieces of the history of this area, see the documents in Appendix B and also: Arns 1998; Bernstein 1984; Crawford 1991; Eckert and Schubert 1990; Eisler 1989; Gertner 2012; Gimbel 1990a; Handel 1999; Hicks 2012; Hilsch 1939; Hilsch and Pohl 1938; Hoddeson et al. 1992; Hoddeson and Daitch 2002; Medawar and Pyke 2000; Metzler 2020; Mertz 1946; Nagel 2006; Noll and Geselowitz 2011; Pierce 1975; Rhoads 2005; Riordan and Hoddeson 1997; Sarkar et al. 2006; Saxena 2009; Sullivan 1949; Sze 1991; Teichmann 1988; Warnow-Blewett and Teichmann 1992.

There is a great need for someone to write a comprehensive and scientifically detailed history of German-speaking contributions to the combined area of solid state physics and microelectronics. Such a history should include all of the creators, creations, and evidence listed in this section and in Appendix B, and draw upon further archival research to solve many of the remaining mysteries.

As shown in upper part of Fig. 6.65, electrons belong to different energy levels, or energy bands, depending on whether the electrons behave like waves with peaks between the ions (higher energy, conduction band) or like waves with peaks at the ions (lower energy, valence band). In the illustration, electrons moving through a simple one-dimensional lattice of positively charged ions behave as standing waves with a wave function $\Psi(x)$. The magnitude of the wave function squared, $|\Psi(x)|^2$, represents the probability that the electrons will be at a given location, so electrons will usually be found near the antinodes (maxima) of the standing waves. If the electron wave function has antinodes between the ion locations as in the upper graph, the negatively charged electrons will tend to be found far away from positively charged ions, so they will have higher energies. If the electron wave function has antinodes near the ion locations, the negatively charged electrons will tend to be found very close to the positively charged ions, so they will have lower energies. Thus there are different possible levels or bands of energies for the electrons, and they are separated by an energy band gap.

The lower part of Fig. 6.65 is a schematic illustration of the occupation of electron energy bands in metals, insulators, semiconductors, and semimetals:

- In metals, an energy band is 10–90% filled. That provides plenty of electrons in the band, but it leaves them lots of nearby vacant energy states they can move to in order to run around and conduct electricity.

- In electrical insulators, each band is either completely full or completely empty. Completely full bands do not provide their electrons with nearby vacant states they can move to in order to conduct electricity, and completely empty bands do not have any electrons to conduct electricity. The band gap between the highest filled band and the lowest empty band is large enough that essentially no electrons from the filled band can jump up to the empty band and conduct electricity.

- Semiconductors are very similar to insulators, except that the energy band gap between the highest filled band (the valence band) and the lowest empty band (the conduction band) is much smaller. Because the band gap is smaller, a small but significant number of electrons can jump up to the conduction band and conduct electricity. These electrons leave behind vacant states in the valence band; the vacant states are called "holes" and act like positive charge-carrying particles.

- Just like semiconductors, semimetals also have a small but significant number of electrons in one band and a corresponding collection of holes in another. However, in semimetals, this effect is due to a negative energy band gap between two bands; an essentially full band overlaps in energy with an essentially empty band, causing some electrons to leave the full energy band and occupy lower energy states in the nearly empty band.

While the ions cannot move as freely as the electrons in a solid, they can vibrate in place, and those vibrations can carry energy. By considering the motions of both the electrons and the ions, solid state physics is able to explain the electrical, magnetic, optical, and thermal properties of solid materials.

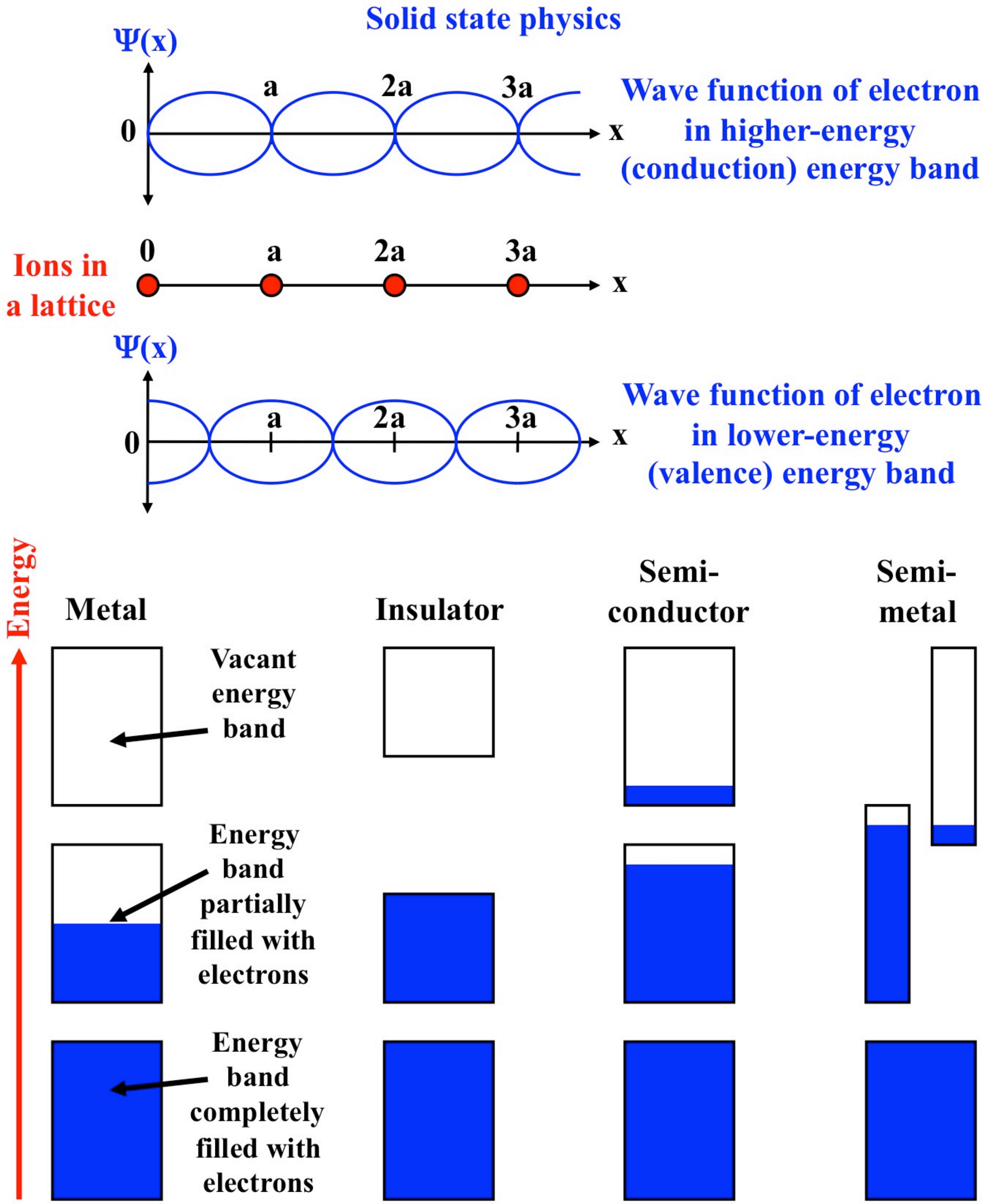


Figure 6.65: Solid state physics, the basic science underlying microelectronics, describes the motions of negatively charged electrons and positively charged ions in crystal lattices. Electrons belong to different energy levels, or energy bands, depending on whether the electrons behave like waves with peaks between the ions (higher energy, conduction band) or with peaks at the ions (lower energy, valence band). Metals have a band partially full of electrons, with plenty of room for them to gain energy and run around. Electrical insulators have bands filled with electrons, and a large energy gap separating those from unfilled bands where they could run around. Semiconductors and semimetals have bands that can be more or less full, depending on the conditions.

In a crystalline solid, the ions are arranged in a three-dimensional periodic pattern or lattice, which has a large effect on the properties of the solid. For different solids with different crystal shapes, those three-dimensional lattice structures can be quite complex. Real crystals often have imperfections such as individual ions that have been knocked out of their correct locations within the lattice. Such lattice defects often absorb certain colors of visible light and are known even in the English-speaking physics community as "F centers" for the German word for color, Farbe.

Some creators who made major contributions to solid state physics are shown in Figs. 6.66–6.70.

Franz Ernst Neumann (German, 1798–1895) was one of the first scientists to make a detailed study of the optical behavior of crystals based on their composition and shapes.

Woldemar Voigt (German, 1850–1919) made contributions to several areas of physics and wrote the first textbook on solid state physics (*Lehrbuch der Kristallphysik*) in 1910.

Arthur Schoenflies (German, 1853–1928) applied advanced mathematical methods such as group theory to the analysis of crystal structures. "Schoenflies notation" is still widely utilized in crystallography and solid state physics.

Eugene Wigner (Hungarian, 1902–1995) greatly extended the group theory methods of Schoenflies with applications in solid state physics and particle physics. He won a Nobel Prize in Physics in 1963 for this work (p. 1546).

Hendrik Antoon Lorentz (Dutch, 1853–1928) used what were then the latest ideas about electromagnetic waves and electrons to create one of the first mathematical models for the electrical and optical properties of solids. He won the Nobel Prize in Physics in 1902 (p. 899).

Paul Drude (German, 1863–1906) also created a mathematical model for electrons in solids. Although the Drude model only considered classical mechanics and electromagnetism, it can be used to analyze and obtain the correct expressions for several important solid state phenomena.

Gustav Wiedemann (German, 1826–1899) and Rudolph Franz (German, 1826–1902) measured the thermal conductivity and the electrical conductivity of metals at different temperatures. They showed empirically that the ratio of the thermal and electrical conductivities increased in direct proportion to the temperature, which came to be called the Wiedemann-Franz law. While the Drude model could explain many properties of solids, it could not correctly explain the Wiedemann-Franz law.

Wolfgang Pauli (Austrian, 1900–1958) showed that electrons obey what is now called the Pauli exclusion rule; every electron in an atom, a solid, or other system is an individualist that refuses to do exactly the same thing as any other electron in that system. For this discovery, Pauli won the Nobel Prize in Physics in 1945 (p. 907).

Arnold Sommerfeld (German, 1868–1951) greatly improved the Drude model by using the Pauli exclusion principle to explain the behavior of electrons in metals. The resulting Sommerfeld or Drude-Sommerfeld model of free electrons yielded theoretical predictions that agreed with the experimental measurements of the Wiedemann-Franz law.

Max Born (German, 1882–1970) wrote an early textbook (*Dynamik der Kristallgitter*) on solid state physics in 1915, and contributed to the subject further as one of the pioneers of quantum physics in the 1920s. He won the Nobel Prize in Physics in 1954 (p. 904).

Felix Bloch (Swiss, 1905–1983) incorporated the wave-like behavior of electrons into models of solids, and the mathematical wave functions of electrons in solids became known as Bloch functions. Bloch won a Nobel Prize in Physics in 1952 (p. 1527).

Ralph Kronig (German, 1904–1995) extended Felix Bloch's calculations of the wave-like behavior of electrons in solids; the updated theory later became known as the Kronig-Penney model. Kronig was also one of the first physicists to propose electron spin. Kronig and Hendrik Anthony Kramers (Dutch, 1894–1952) independently developed the Kramers-Kronig relations for the optical and electronic properties of solids.

Gregory Wannier (Swiss, 1911–1983) further improved the calculations of the wave-like behavior of electrons in solids, resulting in the Wannier functions. With Hendrik Kramers, he also discovered the Kramers-Wannier duality for the magnetic properties of solids.

Wilhelm Lenz (German, 1888–1957) and Ernst Ising (German, 1900–1998) developed what became known as the Ising model to explain the magnetic properties of solids.

Walther Nernst (German, 1864–1941) made important contributions to the statistical physics and thermal properties of solids. He won the Nobel Prize in Chemistry in 1920 (p. 921).

Peter Debye (Dutch, 1884–1966) calculated the effects of vibrations of the ions in a crystal lattice on the thermal properties of the crystal. He won a Nobel Prize in Chemistry in 1936 (p. 922).

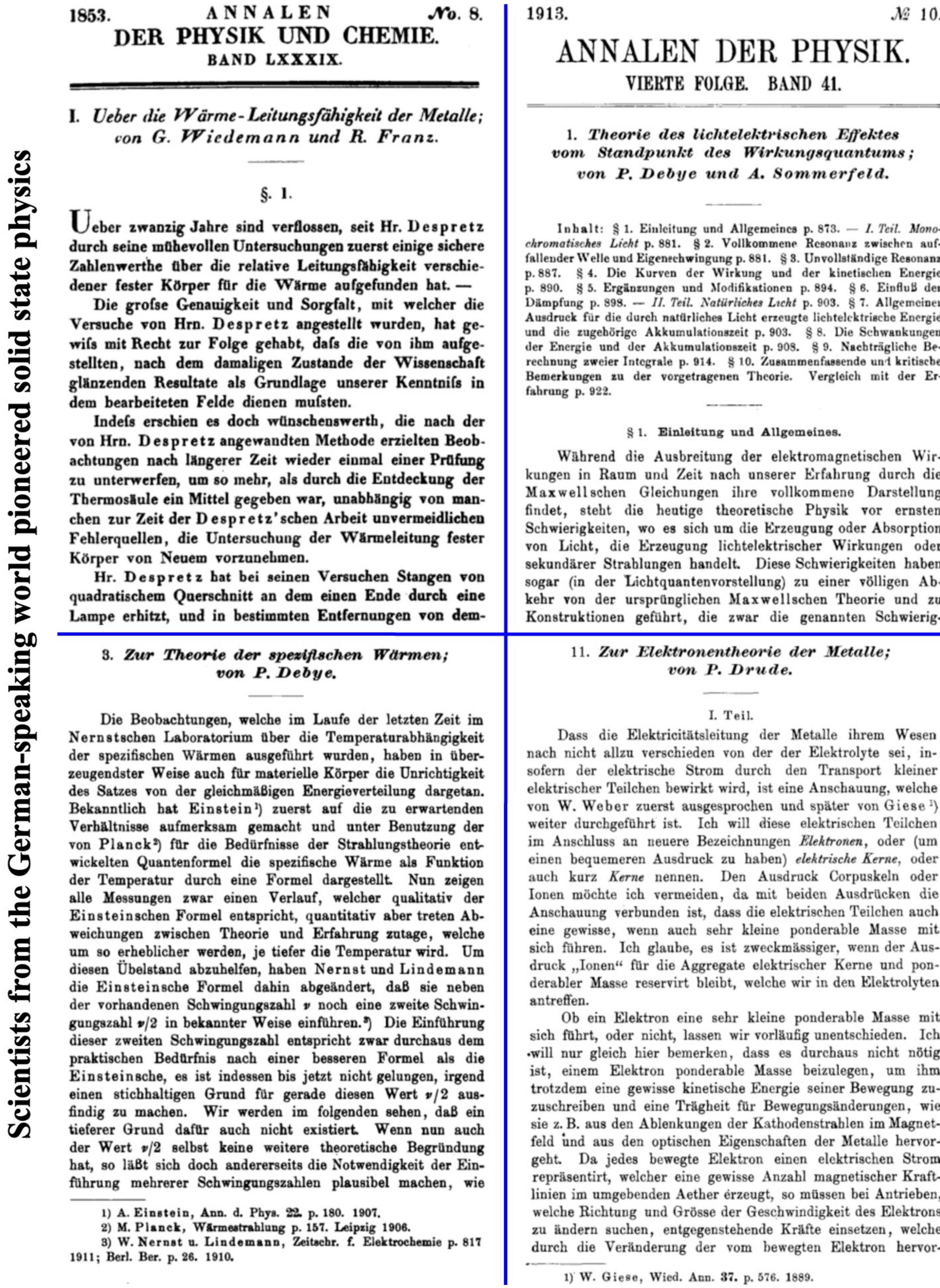
Erwin Madelung (German, 1881–1972) modeled the electrostatic effects of all the ions on an individual ion or on the electrons, resulting in what is now known as the Madelung constant.

Rudolf Peierls (German, 1907–1995) made many major discoveries in solid state physics, including the behavior of the positive "holes" left behind by negative electrons that have left atoms, the properties of phonons or vibrations of the ion lattice, and the shapes of repeating zones in momentum space corresponding to the shapes of repeated crystal shapes in regular space (a fundamentally important discovery that was incorrectly later attributed to Léon Brillouin).

Walther Kossel (German, 1888–1956) studied the structure, bonding, and growth of crystals. He was the son of Albrecht Kossel (p. 91).

Hans Bethe (German, 1906–2005) wrote his doctoral thesis on solid state physics and continued to make new discoveries in the field until after World War II. He won a Nobel Prize in Physics in 1967 (p. 1553).

Georg Joos (German, 1894–1959) gathered a wide variety of solid state physics theories and experiments and assimilated them into organized textbooks that taught several generations of physicists.


Scientists from the German-speaking world pioneered solid state physics

1853. ANNALEN DER PHYSIK UND CHEMIE. No. 8.
BAND LXXXIX.

I. *Ueber die Wärme-Leitungsfähigkeit der Metalle; von G. Wiedemann und R. Franz.*

§. 1.

Ueber zwanzig Jahre sind verflossen, seit Hr. Despretz durch seine mühevollen Untersuchungen zuerst einige sichere Zahlenwerthe über die relative Leitungsfähigkeit verschiedener fester Körper für die Wärme aufgefunden hat. —

Die grofse Genauigkeit und Sorgfalt, mit welcher die Versuche von Hrn. Despretz angestellt wurden, hat gewifs mit Recht zur Folge gehabt, dafs die von ihm aufgestellten, nach dem damaligen Zustande der Wissenschaft glänzenden Resultate als Grundlage unserer Kenntnifs in dem bearbeiteten Felde dienen mufsten.

Indefs erschien es doch wünschenswerth, die nach der von Hrn. Despretz angewandten Methode erzielten Beobachtungen nach längerer Zeit wieder einmal einer Prüfung zu unterwerfen, um so mehr, als durch die Entdeckung der Thermosäule ein Mittel gegeben war, unabhängig von manchen zur Zeit der Despretz'schen Arbeit unvermeidlichen Fehlerquellen, die Untersuchung der Wärmeleitung fester Körper von Neuem vorzunehmen.

Hr. Despretz hat bei seinen Versuchen Stangen von quadratischem Querschnitt an dem einen Ende durch eine Lampe erhitzt, und in bestimmten Entfernungen von dem-

1913. № 10.
ANNALEN DER PHYSIK.
VIERTE FOLGE. BAND 41.

1. *Theorie des lichtelektrischen Effektes vom Standpunkt des Wirkungsquantums; von P. Debye und A. Sommerfeld.*

Inhalt: § 1. Einleitung und Allgemeines p. 873. — *I. Teil. Monochromatisches Licht* p. 881. § 2. Vollkommene Resonanz zwischen auffallender Welle und Eigenschwingung p. 881. § 3. Unvollständige Resonanz p. 887. § 4. Die Kurven der Wirkung und der kinetischen Energie p. 890. § 5. Ergänzungen und Modifikationen p. 894. § 6. Einfluß der Dämpfung p. 898. — *II. Teil. Natürliches Licht* p. 903. § 7. Allgemeiner Ausdruck für die durch natürliches Licht erzeugte lichtelektrische Energie und die zugehörige Akkumulationszeit p. 903. § 8. Die Schwankungen der Energie und der Akkumulationszeit p. 908. § 9. Nachträgliche Berechnung zweier Integrale p. 914. § 10. Zusammenfassende und kritische Bemerkungen zu der vorgetragenen Theorie. Vergleich mit der Erfahrung p. 922.

§ 1. Einleitung und Allgemeines.

Während die Ausbreitung der elektromagnetischen Wirkungen in Raum und Zeit nach unserer Erfahrung durch die Maxwellschen Gleichungen ihre vollkommene Darstellung findet, steht die heutige theoretische Physik vor ernsten Schwierigkeiten, wo es sich um die Erzeugung oder Absorption von Licht, die Erzeugung lichtelektrischer Wirkungen oder sekundärer Strahlungen handelt. Diese Schwierigkeiten haben sogar (in der Lichtquantenvorstellung) zu einer völligen Abkehr von der ursprünglichen Maxwellschen Theorie und zu Konstruktionen geführt, die zwar die genannten Schwierig-

3. *Zur Theorie der spezifischen Wärmen; von P. Debye.*

Die Beobachtungen, welche im Laufe der letzten Zeit im Nernstschen Laboratorium über die Temperaturabhängigkeit der spezifischen Wärmen ausgeführt wurden, haben in überzeugendster Weise auch für materielle Körper die Unrichtigkeit des Satzes von der gleichmäßigen Energieverteilung dargetan. Bekanntlich hat Einstein[1]) zuerst auf die zu erwartenden Verhältnisse aufmerksam gemacht und unter Benutzung der von Planck[2]) für die Bedürfnisse der Strahlungstheorie entwickelten Quantenformel die spezifische Wärme als Funktion der Temperatur durch eine Formel dargestellt. Nun zeigen alle Messungen zwar einen Verlauf, welcher qualitativ der Einsteinschen Formel entspricht, quantitativ aber treten Abweichungen zwischen Theorie und Erfahrung zutage, welche um so erheblicher werden, je tiefer die Temperatur wird. Um diesen Übelstand abzuhelfen, haben Nernst und Lindemann die Einsteinsche Formel dahin abgeändert, daß sie neben der vorhandenen Schwingungszahl ν noch eine zweite Schwingungszahl $\nu/2$ in bekannter Weise einführen.[3]) Die Einführung dieser zweiten Schwingungszahl entspricht zwar durchaus dem praktischen Bedürfnis nach einer besseren Formel als die Einsteinsche, es ist indessen bis jetzt nicht gelungen, irgend einen stichhaltigen Grund für gerade diesen Wert $\nu/2$ ausfindig zu machen. Wir werden im folgenden sehen, daß ein tieferer Grund dafür auch nicht existiert. Wenn nun auch der Wert $\nu/2$ selbst keine weitere theoretische Begründung hat, so läßt sich doch andererseits die Notwendigkeit der Einführung mehrerer Schwingungszahlen plausibel machen, wie

1) A. Einstein, Ann. d. Phys. **22**. p. 180. 1907.
2) M. Planck, Wärmestrahlung p. 157. Leipzig 1906.
3) W. Nernst u. Lindemann, Zeitschr. f. Elektrochemie p. 817 1911; Berl. Ber. p. 26. 1910.

11. *Zur Elektronentheorie der Metalle; von P. Drude.*

I. Teil.

Dass die Elektricitätsleitung der Metalle ihrem Wesen nach nicht allzu verschieden von der der Elektrolyte sei, insofern der elektrische Strom durch den Transport kleiner elektrischer Teilchen bewirkt wird, ist eine Anschauung, welche von W. Weber zuerst ausgesprochen und später von Giese[1]) weiter durchgeführt ist. Ich will diese elektrischen Teilchen im Anschluss an neuere Bezeichnungen *Elektronen*, oder (um einen bequemeren Ausdruck zu haben) *elektrische Kerne*, oder auch kurz *Kerne* nennen. Den Ausdruck Corpuskeln oder Ionen möchte ich vermeiden, da mit beiden Ausdrücken die Anschauung verbunden ist, dass die elektrischen Teilchen auch eine gewisse, wenn auch sehr kleine ponderable Masse mit sich führen. Ich glaube, es ist zweckmässiger, wenn der Ausdruck „Ionen" für die Aggregate elektrischer Kerne und ponderabler Masse reservirt bleibt, welche wir in den Elektrolyten antreffen.

Ob ein Elektron eine sehr kleine ponderable Masse mit sich führt, oder nicht, lassen wir vorläufig unentschieden. Ich will nur gleich hier bemerken, dass es durchaus nicht nötig ist, einem Elektron ponderable Masse beizulegen, um ihm trotzdem eine gewisse kinetische Energie seiner Bewegung zuzuschreiben und eine Trägheit für Bewegungsänderungen, wie sie z. B. aus den Ablenkungen der Kathodenstrahlen im Magnetfeld und aus den optischen Eigenschaften der Metalle hervorgeht. Da jedes bewegte Elektron einen elektrischen Strom repräsentirt, welcher eine gewisse Anzahl magnetischer Kraftlinien im umgebenden Aether erzeugt, so müssen bei Antrieben, welche Richtung und Grösse der Geschwindigkeit des Elektrons zu ändern suchen, entgegenstehende Kräfte einsetzen, welche durch die Veränderung der vom bewegten Elektron hervor-

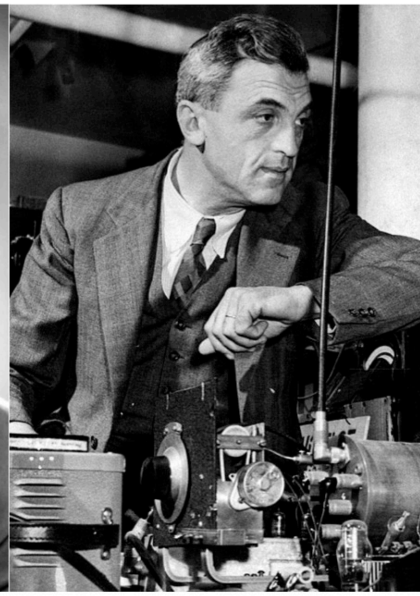
1) W. Giese, Wied. Ann. **37**. p. 576. 1889.

Figure 6.66: Scientists from the German-speaking world pioneered solid state physics, as illustrated by these examples of some of their original papers [Wiedemann and Franz 1853; Debye and Sommerfeld 1913; Debye 1912; Drude 1900].

Solid state physics

Hans Bethe
(1906–2005)

Felix Bloch
(1905–1983)



Max Born
(1882–1970)

Peter Debye
(1884–1966)

Paul Drude
(1863–1906)

Rudolph Franz
(1826–1902)

Figure 6.67: Some creators who made major contributions to solid state physics include Hans Bethe, Felix Bloch, Max Born, Peter Debye, Paul Drude, and Rudolph Franz.

Solid state physics

Figure 6.68: Other creators who made major contributions to solid state physics include Ernst Ising, Georg Joos, Walther Kossel, Hendrik Anthony Kramers, Ralph Kronig, and Wilhelm Lenz.

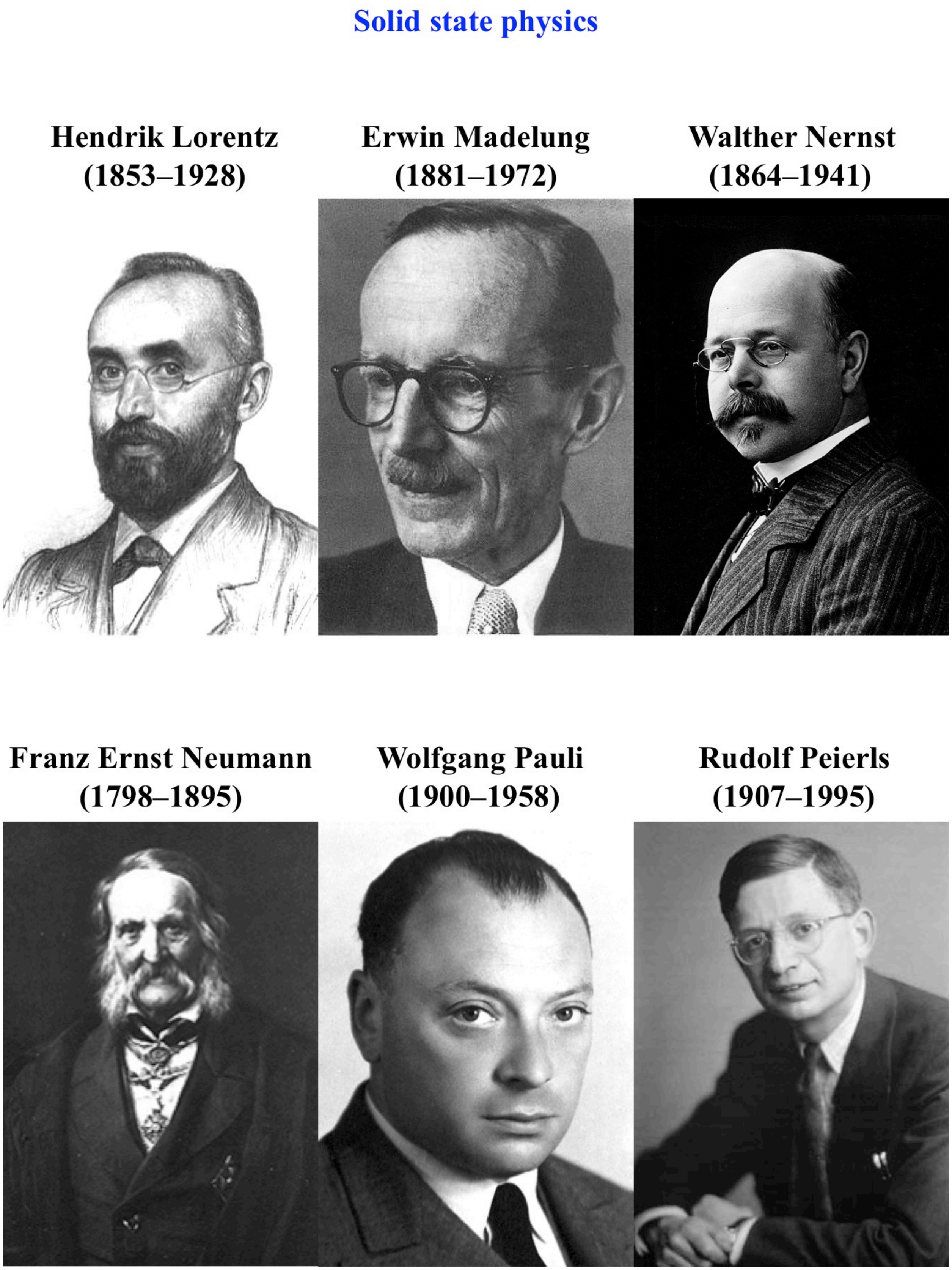


Figure 6.69: Other creators who made major contributions to solid state physics include Hendrik Antoon Lorentz, Erwin Madelung, Walther Nernst, Franz Ernst Neumann, Wolfgang Pauli, and Rudolf Peierls.

Solid state physics

Arthur Schoenflies (1853–1928)

Arnold Sommerfeld (1868–1951)

Woldemar Voigt (1850–1919)

Gregory Wannier (1911–1983)

Gustav Wiedemann (1826–1899)

Eugene Wigner (1902–1995)

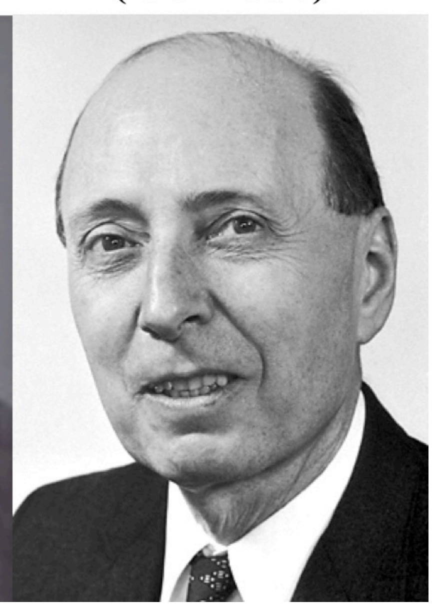


Figure 6.70: Other creators who made major contributions to solid state physics include Arthur Schoenflies, Arnold Sommerfeld, Woldemar Voigt, Gregory Wannier, Gustav Wiedemann, and Eugene Wigner.

6.5.2 Semiconductor Materials and Devices

Harnessing solid state physics effects, especially those in semiconductors, led to the development of numerous microelectronic devices for various applications. Scientists from the greater German-speaking world took the lead in that area.

Karl Ferdinand Braun (German, 1850–1918) invented and demonstrated semiconductor diodes in 1874, using point contacts and crystals of metal sulfides for his first diodes (Fig. 6.71). Braun continued to experiment with and improve semiconductor diodes over the following years and ultimately harnessed them to develop radio systems. Braun also produced many other innovations in electronics, including oscilloscopes and phased array antennas. He won the Nobel Prize in Physics in 1909 for his radio-related research (p. 987).

In 1893, Julius Elster (German, 1854–1920) and Hans Geitel (German, 1855–1923) invented the semiconductor photoelectric cell, which could detect and measure the amount of light and produce a corresponding electrical output signal (Fig. 6.72). They continued to test photoelectric cells and devise applications for them for at least a decade, launching what became a large German industry. Elster and Geitel also made important discoveries on a wide variety of other topics in atmospheric physics, astronomy, nuclear physics, and other scientific areas.

In 1916, Jan Czochralski (Polish/German, 1885–1953) at the huge AEG electronics company developed a method for growing single, large, high-purity crystals of semiconductors or other materials (Fig. 6.73). The Czochralski method, as it became known, is now used worldwide to prepare semiconductor crystals, which are usually then sliced into wafers and chips.

Bernhard Gudden (German, 1892–1945) and Robert Pohl (German, 1884–1976) developed improved photoelectric cells and also electroluminescent semiconductor devices, the direct forerunners of light emitting diodes (LEDs), during the period 1919–1923 (pp. 1113, 1115). After that time, both Gudden and Pohl separately continued to conduct research on advanced semiconductor devices and microelectronics through World War II, including developing prototype transistors.

Karl Ferdinand Braun (1850–1918) invented semiconductor diodes (1874), improved radio transmitters and receivers (1897), cathode ray tubes and oscilloscopes (1897), phased array antennas (1905), etc.

VI. *Ueber die Stromleitung durch Schwefelmetalle; von Ferdinand Braun.*

***Annalen der Physik* 229:12:556-563 (1875)**

Im 9. Hefte dieser Annalen (Bd. 153) befindet sich eine Arbeit von Herwig: „Einige Beobachtungen über das Verhalten von Eisen- und Stahlstäben im galvanischen Strome", wonach diese Körper je nach Richtung, Intensität und Dauer des Stromes demselben verschiedenen Widerstand entgegensetzen. Die Aenderungen schwanken im Allgemeinen zwischen $\frac{1}{3000}$ und $\frac{1}{20000}$ des ganzen Werthes. Diese Arbeit veranlaſst mich, einiges über ähnliche Erfahrungen mitzutheilen, welche ich bei anderen Körpern

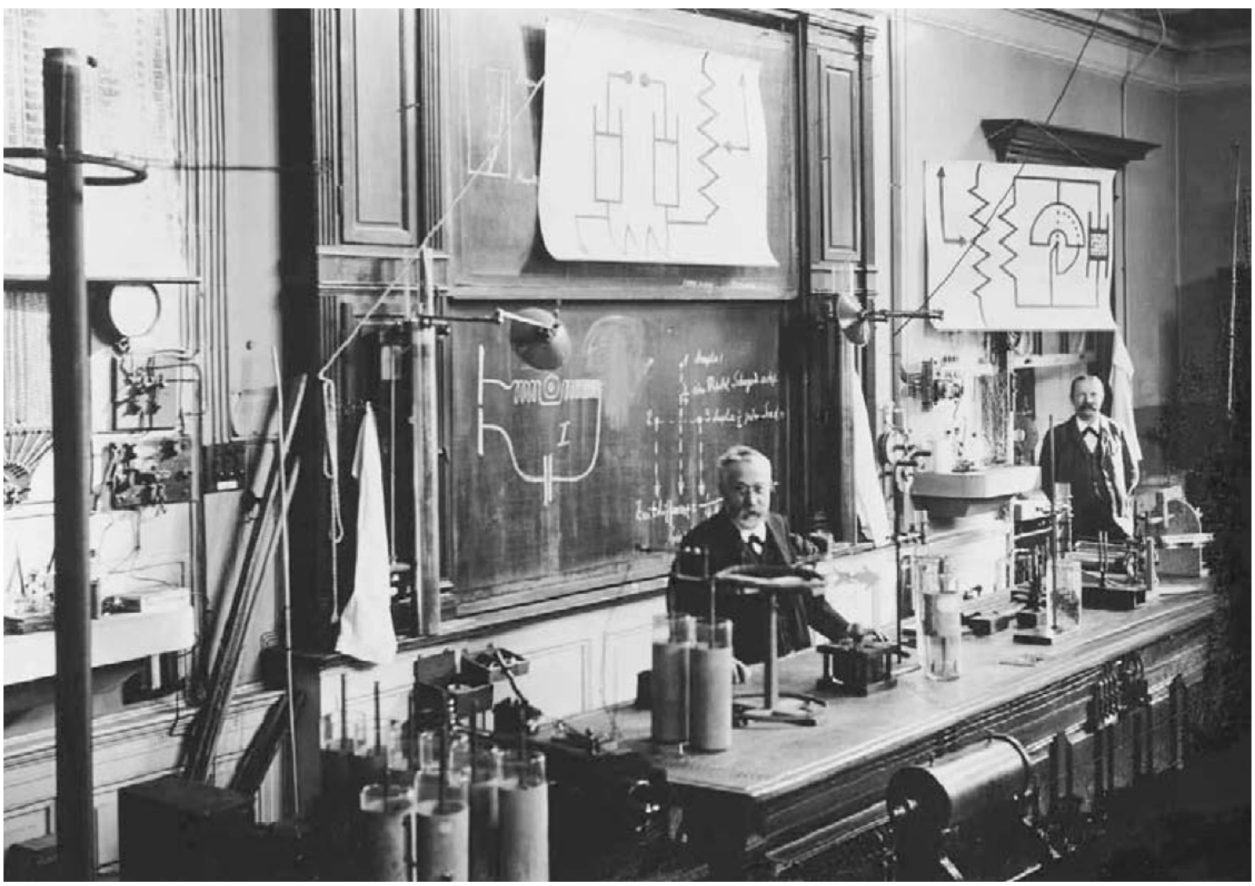


Figure 6.71: Karl Ferdinand Braun invented semiconductor diodes (1874), improved radio transmitters and receivers (1897), cathode ray tubes and oscilloscopes (1897), phased array antennas (1905), etc.

Julius Elster (left, 1854–1920) and Hans Geitel (right, 1855–1923) invented the photoelectric cell (1893)

IV. ***Ueber die Vergleichung von Lichtstärken auf photoelectrischem Wege;***
von J. Elster und H. Geitel.
Annalen der Physik 284:4:625 (1893)

Dass es möglich ist, die Intensität ultravioletten Lichtes durch die photoelectrische Zerstreuung an Kathodenflächen von amalgamirtem Zink in der freien Luft mit einiger Annäherung zu messen, glauben wir vor kurzem nachgewiesen zu haben.[1])

Die Methode war eine electrostatische und die Vergleichung der Lichtintensitäten geschah durch die Differenz der Logarithmen des vor und nach einer constanten Expositionszeit gemessenen negativen Potentials einer lichtempfindlichen Zinkkugel.

Die zu Grunde gelegte und durch den Versuch bestätigte Annahme lässt sich dahin zusammenfassen, dass die nur durch das Licht bewirkte Zerstreuung der negativen Electricität bei constanter electrischer Dichtigkeit auf der Zinkfläche der Lichtintensität proportional sei. Die geringe Empfindlichkeit des Zinks gegen Strahlen grösserer Wellenlänge macht es nun unmöglich, auf diese Art Lichtstärken zu vergleichen, die der Hauptsache nach aus physiologisch wirksamen Bestandtheilen zusammengesetzt sind.

Man muss, um dies zu erreichen, zu reinen Oberflächen der Alkalimetalle greifen. Da man genöthigt ist, diese Substanzen vor dem Sauerstoff der Luft geschützt in Glasrecipienten einzuschliessen, so verliert man die Möglichkeit einer freien Exposition, und auch die Anwendung der electrostatischen Methode wird durch die Anwesenheit des Recipienten beeinträchtigt. Dagegen gewinnt man, wie wir schon früher angegeben, den Vortheil, durch passende Wahl des Gasdrucks im Recipienten die Empfindlichkeit auf das höchste erreichbare Maass steigern zu können.

Verbindet man nun die Alkalimetallfläche mit dem negativen, die gegenüberstehende Platin- oder Aluminiumelectrode

1) J. Elster u. H. Geitel, Wied. Ann. **48.** p. 338. 1893.

Figure 6.72: Julius Elster and Hans Geitel invented the photoelectric cell in 1893.

Jan Czochralski (1885–1953)
Method for growing semicon-ductor crystals/wafers (1916)

Ein neues Verfahren zur Messung der Kristallisationsgeschwindigkeit der Metalle.

Von

J. Czochralski.

(Mit 3 Figuren im Text.)

(Eingegangen am 19. 8. 16.)

Die Bestimmung der Kristallisationsgeschwindigkeit (KG) geht, wie Tammann gezeigt hat[1]), bei den nichtmetallischen Stoffen in der Regel glatt von statten. Bei den Metallen konnte dagegen infolge deren Undurchsichtigkeit das Tammannsche Verfahren nicht angewandt werden. Einige Untersuchungsergebnisse des Verfassers legten es nahe, die Messung der Kristallisationsgeschwindigkeit von Metallen auf einfache Weise durchzuführen. Das Verfahren beruht auf der Messung der Höchstgeschwindigkeit, mit der man einen dünnen Kristallfaden des betreffenden Metalles aus seiner Schmelze kontinuierlich ziehen kann, ohne dass ein Abreissen des Fadens erfolgt.

Die erforderliche, in Fig. 1 wiedergegebene Vorrichtung besteht aus dem Stativ S, der Führungsscheibe F'' mit den beiden Führungen F' für den Seidenfaden F, an dem ein Mitnehmer M aus Glas für den Kristallfaden K befestigt ist. Die Schmelze Sch befindet sich in einem Holzkohlentiegel H mit einer seitlichen Bohrung für das Thermometer. Durch ein leicht regulierbares Uhrwerk U kann der Seidenfaden F leicht aufwärts und abwärts bewegt werden. Zur Messung der Geschwindigkeit dient der Zeiger Z und die Millimeterskala MS. Um das Anhaften der Schmelze an dem Mitnehmer M zu erleichtern, versieht man dessen Spitze a (Fig. 2) durch Reiben in dem halberstarrten breiigen Metall mit einem dünnen Metallüberzug.

Für die Versuchsausführung wird der Mitnehmer M in das flüssige, etwas überhitzte Metall getaucht und der Apparat, nachdem sich die Temperatur des Schmelzpunktes eingestellt hat, in Tätigkeit gesetzt. Infolge der Kapillarkraft zieht der Mitnehmer M zunächst eine kleine

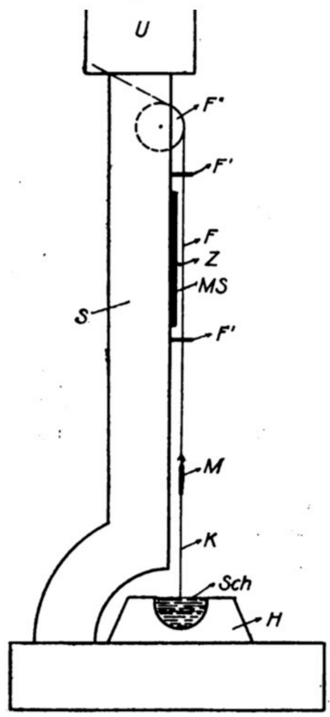


Fig. 1.

Fig. 2.

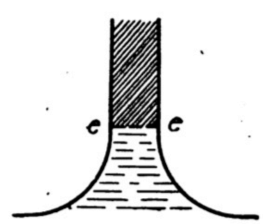


Fig. 3.

Figure 6.73: Jan Czochralski at AEG developed a method for growing semiconductor crystals and wafers in 1916.

6.5.3 Transistors

According to official histories, the first transistor was invented at Bell Laboratories in late 1947 and early 1948 by John Bardeen (American, 1908–1991), Walter Brattain (American, 1902–1987), and William Shockley (American, 1910–1989). However, there is significant evidence that at least 12 different groups of German-speaking scientists may have invented transistors earlier:

1. Julius Edgar Lilienfeld (Austrian, 1882–1963) invented an improved X-ray tube in 1912, the field effect transistor in 1925, and an improved electrolytic capacitor in 1931, as shown on pp. 1093–1061 and 2669–2689. Lilienfeld filed several patent applications on his field effect transistor during the period 1925–1928. The great level of detail in those applications regarding the production and performance of such transistors suggests that he built and tested them [Arns 1998; Crawford 1991], although exactly what results he achieved are not clear from currently available documents. Much later, Bell Laboratories secretly built functioning devices based directly on Lilienfeld's patents, lending further support to the view that the patents were based on Lilienfeld's own successful experimentation [Arns 1998; Shockley and Pearson 1948]. In the 1920s Lilienfeld moved to the United States, where he married an American woman. It appears that he was unsuccessful in finding sufficient support for his transistor idea in the United States. In the 1930s Lilienfeld and his wife moved to the island of Saint Thomas in the Caribbean, where they lived the rest of their lives.

2. Oskar Heil (German, 1908–1994) filed a detailed patent application on field effect transistors in 1934; see pp. 1063 and 2691–2693. Currently it is unclear just what experimental work Heil may have done on the concept either before or after filing the patent application, or whether other German-speaking scientists may have taken up the ideas proposed in the application.

3. Gilles Holst (Dutch, 1886–1968) and Willem Christiaan van Geel (Dutch, 1895–1967) filed a German patent application on transistors in 1935. See pp. 1065–1066 and 2698–2701. Holst was the research director at the Philips Eindhoven laboratory [Van Delft 2014], and van Geel was an expert there on metal and semiconductor materials. Both were nominated for the Nobel Prize in Physics but never won.[12] Holst was also one of the inventors of the sodium vapor lamp in 1932 (p. 980). Philips Eindhoven was closely tied to the rest of the predominantly German-speaking research world from the late nineteenth century through World War II, including work on electronics, communications, and directed energy beams.[13] More archival research is needed to determine how far the work of Holst and van Geel got by 1945, or how much it was influenced by or influenced transistor-related work by other research groups.

[12]https://www.nobelprize.org/nomination/archive/show.php?id=4874

https://www.nobelprize.org/nomination/archive/show.php?id=4936

[13]See for example: CIOS III-1; CIOS VI-26, 27; CIOS X-13; CIOS XI-10; CIOS XII-22.

4. Rudolf Hilsch (German, 1903–1972) and Robert Pohl demonstrated a proof-of-concept point-contact transistor in 1938 [Hilsch and Pohl 1938]. As shown on pp. 1067 and 2703–2704, like a modern transistor, this solid-state semiconductor device had three electrodes, with the current flow into the middle electrode (the base, in modern terminology) controlling and greatly amplified by the much larger current flow between the other two electrodes. For the 1938 experiments, that signal amplification was approximately a factor of 20. These results were extremely impressive, but the reason they are best described as "proof of concept" is that they were obtained in a material (a potassium bromide crystal) that became a good semiconductor only at a very high temperature (490^{o}C) and voltages (100–150 Volts), which would not be practical for use in normal electronic circuits.

Hilsch recognized those limitations and promptly proposed that the results be replicated by modifying existing room-temperature semiconductor diodes to add a third electrode for the base [Hilsch 1939]:

> Durch diese Messung ist zum erstenmal gezeigt worden, daß man auch in festen Körpern Ströme steuern kann. Die Trägheit der Ströme in diesem "großen" Modell ist naturgemäß groß. Es ist jetzt nur eine Aufgabe der Technik, auch in den dünnen Sperrschichten der technischen Gleichrichter das Steuergitter unterzubringen. Wenn die Lösung dieser Aufgabe gelingt, kann der Dreielektroden-Kristall auch technisch neben dem Dreielektroden-Rohr seine Bedeutung erhalten.

> This measurement has shown for the first time that it is also possible to control currents in solid bodies. The inertia of the currents in this "large" model is naturally large. It is now only a technical task to add the control grid in the thin barrier layers of engineering rectifiers. If the solution to this problem is successful, the three-electrode crystal can also gain technical significance alongside the three-electrode tube.

From available documentation, it is unclear exactly what projects Hilsch worked on between 1939 and the post-war period. Given his determination to replicate the transistor amplifier results in a more practical semiconductor device, and given the extensive wartime work on new and improved semiconductor devices, it seems likely that he would have carried his transistor work further, or collaborated with other scientists to do so. In any event, the 1938 Hilsch and Pohl paper and the 1939 Hilsch paper were published in physics journals that were highly regarded and widely read in the German-speaking world, so they would have encouraged many other scientists (such as those listed below) to try to replicate and extend that work.

5. Erich Habann (German, 1892–1968) filed a very detailed patent application on point-contact transistors, their fabrication, and use in 1942 (pp. 1069 and 2707–2711). The level of detail suggests that Habann may well have already produced and demonstrated such transistors at his Hessenwinkel laboratory. Although documentation on his results is not currently available, it is known that Habann worked on a number of secretive research projects during the war and was well funded by the German military [Nagel 2006].

6. Walter Schottky (Swiss/German, 1886–1976) published detailed analyses of semiconductor properties necessary for transistors in 1942 [Handel 1999]. See pp. 1071 and 2713–2721. All of Schottky's papers were seized by the United States in 1945 and never returned to him or publicly disclosed.

7. Heinrich Welker (German, 1912–1981) and Herbert Mataré (German, 1912–2011) began developing a point-contact transistor in Germany during the war, filed a detailed patent application based on that wartime work on 6 April 1945, and publicly announced their transistor in 1948 in France.[14] See pp. 1073 and 2723–2732.

8. Erwin Weise (German?, 19??–19??) admitted to Allied investigators that he "had demonstrated the possibility of using thin films or control electrodes in semi-conducting materials to provide control of current flow similar to the control of current flow in high vacuum tubes" to create "electronic amplifiers without vacuum" (pp. 1075 and 2734–2745).

9. Frank Rose (German?, 19??–19??), Eberhard Spenke (German, 1905–1992), and Erich Waldkötter (German?, 19??–19??) filed detailed patent applications on transistors in 1949, as shown on pp. 1077 and 2747–2756. Because of the extreme political and financial restrictions on conducting research in Germany after the war, it seems likely that their patent applications were based on wartime work [Handel 1999]. Indeed, large numbers of patent applications on wartime inventions were filed in 1949 when the West German patent office opened.

10. Karl Seiler (German, 1910–1991) and Paul Ludwig Günther (German, 1892–1969) developed methods for designing and fabricating silicon semiconductor devices throughout the war and into the postwar period (pp. 1079 and 2758–2766). Their work was applied to transistors after the war, and it may have been used for that purpose during the war [Handel 1999].

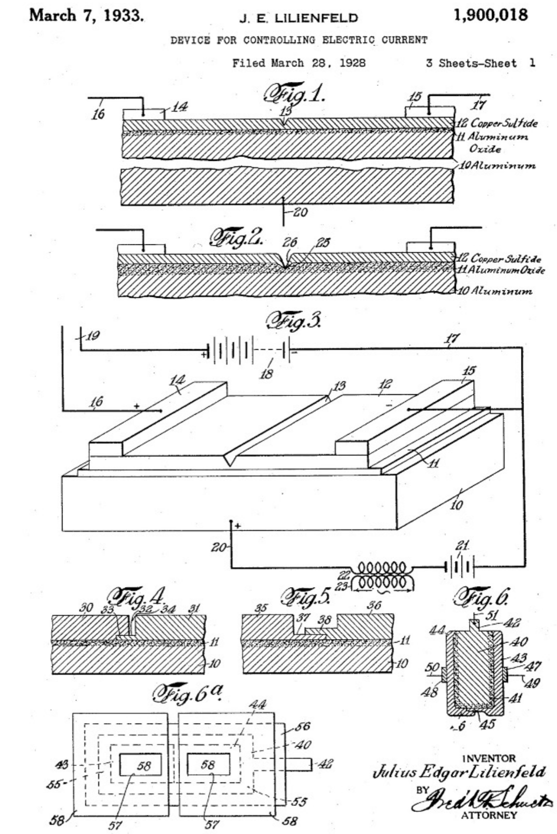
11. Helmar Frank (Moravian, 1919–2015) and Jan Tauc (Bohemian, 1922–2010) worked in very large, secret, German-run laboratories in Tannwald (now Tanvald, Czech Republic) during the war [Lojek 2007]. When Czechoslovakia salvaged what was left of those laboratories and restarted them after the war, one of the first actions that Frank and Tauc carried out was to produce and demonstrate transistors. Those postwar Czech transistors were based at least in part, and quite possibly entirely, on wartime German work (pp. 1081, 2768–2769, 4017, 5585, 5595, and 5631). Both Frank and Tauc continued to develop semiconductor and microelectronics technologies in Czechoslovakia for many years. Frank was interrogated by the United States in 1945 regarding his knowledge of advanced electronics technologies. Tauc eventually moved to the United States.

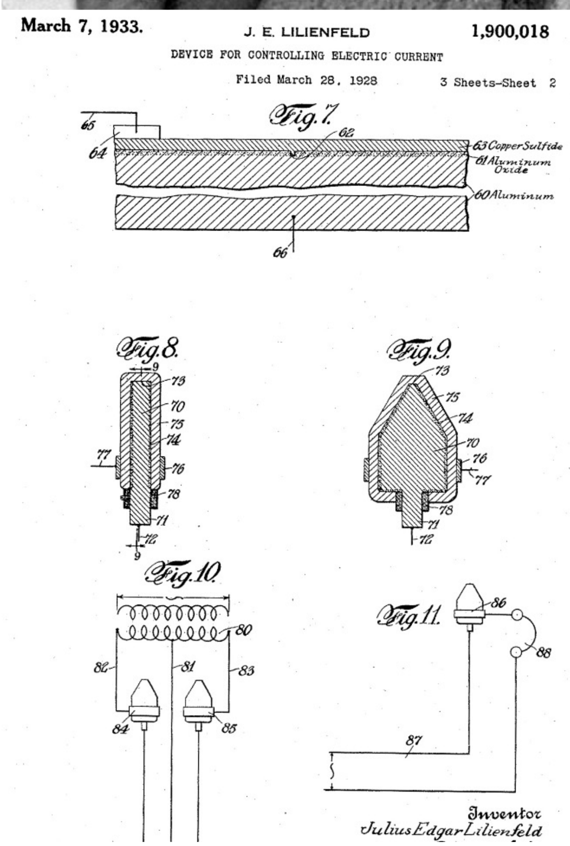
[14] Handel 1999; Ringer and Welker 1948; Riordan 2005; Van Dormael 2004, 2009, 2012.

12. During the war, Bernhard Gudden (German, 1892–1945) and Kurt Lehovec (Bohemian/Austrian/Czech, 1918–2012) ran a secretive and well-funded group that was developing advanced semiconductor devices at Charles University in Prague [Lojek 2007]. After the war, Gudden refused to assist Russian or Russian-backed forces and died in a Czech prison. Lehovec was extensively interrogated by the United States and then moved to the United States, where he filed patents on light emitting diodes, transistors, and integrated circuits. His first U.S. patent application on transistors covered a design that had several advantages over the transistors from Bell Laboratories, and that may well have been based on wartime work that he and Gudden had been conducting. See pp. 1083, 1106, 2769–2775, 2830–2844, and 2907–2922.

In addition to these 12 groups, were there any other German-speaking groups developing transistors, for example at laboratories run by AEG, Askania, Blaupunkt, Fernseh, Loewe Radio, C. Lorenz, Philips, the Reichspost, Siemens, the SS, Telefunken, various universities, or other laboratories in Germany, Austria, Czech territory, Polish territory, or elsewhere? Much more archival research is needed.

Transistors (1)
Julius Edgar Lilienfeld
(1882–1963) invented the
field effect transistor (1925)





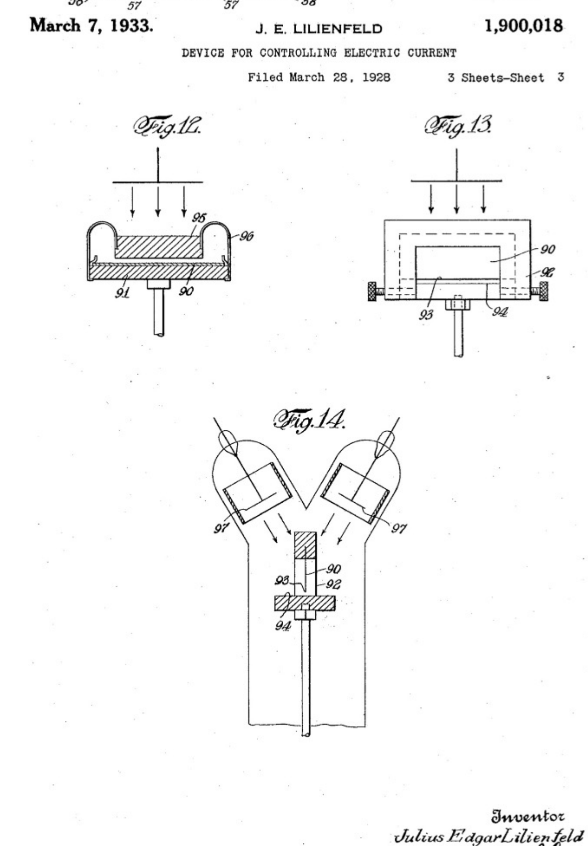
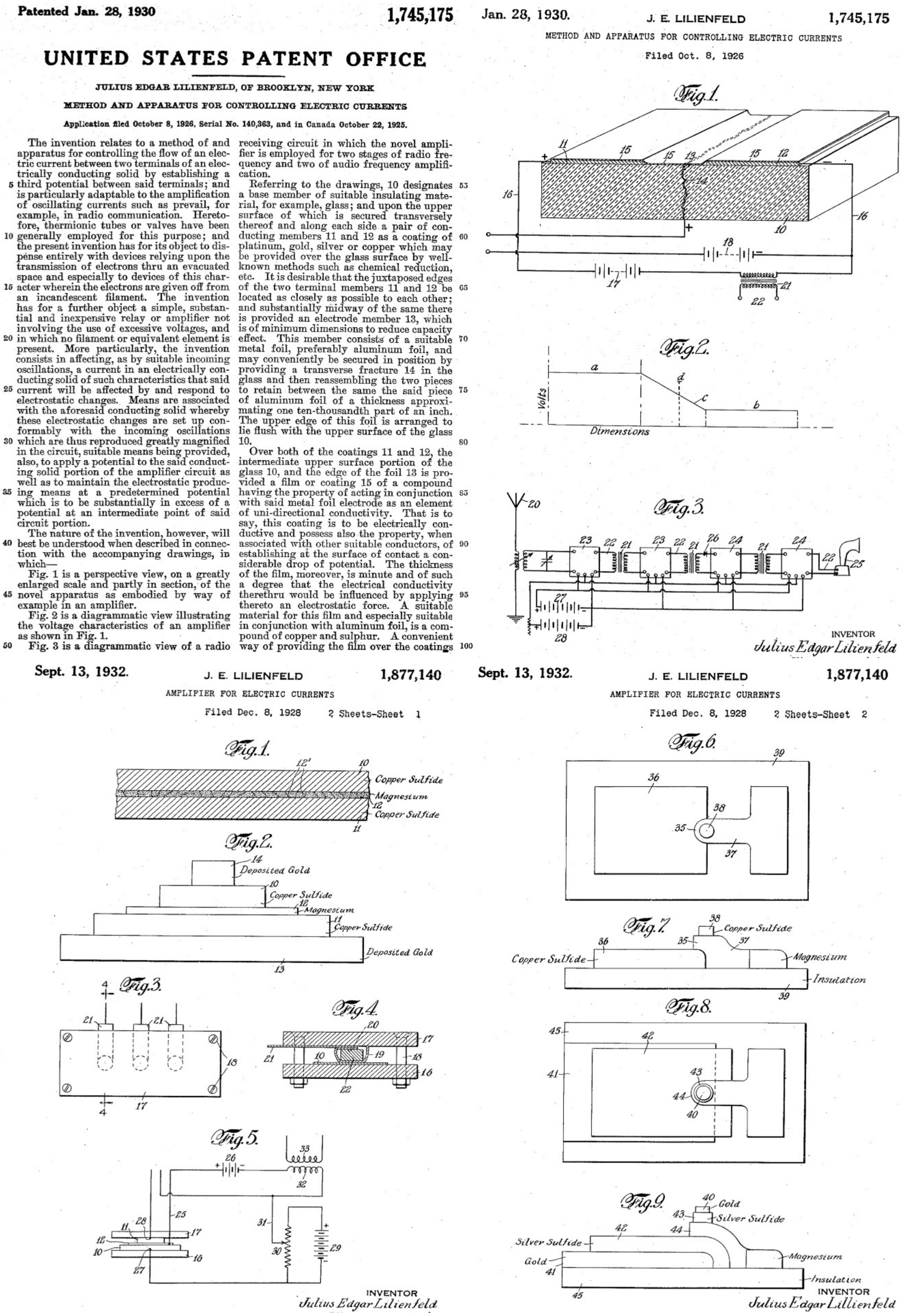


Figure 6.74: Julius Edgar Lilienfeld invented the field effect transistor in 1925 and filed a number of highly detailed patent applications on it.

Transistors (1)
Julius Edgar Lilienfeld (1882–1963) invented the field effect transistor (1925)



Patented Jan. 28, 1930 1,745,175

UNITED STATES PATENT OFFICE

JULIUS EDGAR LILIENFELD, OF BROOKLYN, NEW YORK

METHOD AND APPARATUS FOR CONTROLLING ELECTRIC CURRENTS

Application filed October 8, 1926, Serial No. 140,363, and in Canada October 22, 1925.

The invention relates to a method of and apparatus for controlling the flow of an electric current between two terminals of an electrically conducting solid by establishing a third potential between said terminals; and is particularly adaptable to the amplification of oscillating currents such as prevail, for example, in radio communication. Heretofore, thermionic tubes or valves have been generally employed for this purpose; and the present invention has for its object to dispense entirely with devices relying upon the transmission of electrons thru an evacuated space and especially to devices of this character wherein the electrons are given off from an incandescent filament. The invention has for a further object a simple, substantial and inexpensive relay or amplifier not involving the use of excessive voltages, and in which no filament or equivalent element is present. More particularly, the invention consists in affecting, as by suitable incoming oscillations, a current in an electrically conducting solid of such characteristics that said current will be affected by and respond to electrostatic changes. Means are associated with the aforesaid conducting solid whereby these electrostatic changes are set up conformably with the incoming oscillations which are thus reproduced greatly magnified in the circuit, suitable means being provided, also, to apply a potential to the said conducting solid portion of the amplifier circuit as well as to maintain the electrostatic producing means at a predetermined potential which is to be substantially in excess of a potential at an intermediate point of said circuit portion.

The nature of the invention, however, will best be understood when described in connection with the accompanying drawings, in which—

Fig. 1 is a perspective view, on a greatly enlarged scale and partly in section, of the novel apparatus as embodied by way of example in an amplifier.

Fig. 2 is a diagrammatic view illustrating the voltage characteristics of an amplifier as shown in Fig. 1.

Fig. 3 is a diagrammatic view of a radio receiving circuit in which the novel amplifier is employed for two stages of radio frequency and two of audio frequency amplification.

Referring to the drawings, 10 designates a base member of suitable insulating material, for example, glass; and upon the upper surface of which is secured transversely thereof and along each side a pair of conducting members 11 and 12 as a coating of platinum, gold, silver or copper which may be provided over the glass surface by well-known methods such as chemical reduction, etc. It is desirable that the juxtaposed edges of the two terminal members 11 and 12 be located as closely as possible to each other; and substantially midway of the same there is provided an electrode member 13, which is of minimum dimensions to reduce capacity effect. This member consists of a suitable metal foil, preferably aluminum foil, and may conveniently be secured in position by providing a transverse fracture 14 in the glass and then reassembling the two pieces to retain between the same the said piece of aluminum foil of a thickness approximating one ten-thousandth part of an inch. The upper edge of this foil is arranged to lie flush with the upper surface of the glass 10.

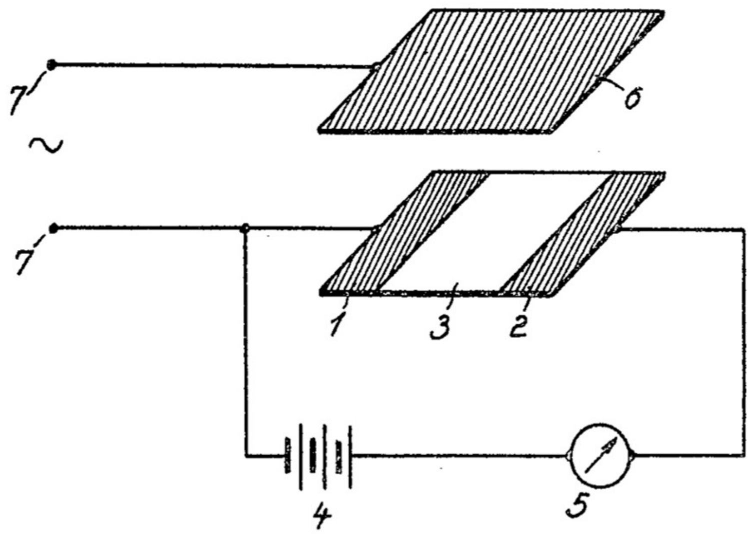
Over both of the coatings 11 and 12, the intermediate upper surface portion of the glass 10, and the edge of the foil 13 is provided a film or coating 15 of a compound having the property of acting in conjunction with said metal foil electrode as an element of uni-directional conductivity. That is to say, this coating is to be electrically conductive and possess also the property, when associated with other suitable conductors, of establishing at the surface of contact a considerable drop of potential. The thickness of the film, moreover, is minute and of such a degree that the electrical conductivity therethru would be influenced by applying thereto an electrostatic force. A suitable material for this film and especially suitable in conjunction with aluminum foil, is a compound of copper and sulphur. A convenient way of providing the film over the coatings

Figure 6.75: Julius Edgar Lilienfeld invented the field effect transistor in 1925 and filed a number of highly detailed patent applications on it.

Transistors (2)

Oskar Heil (1908–1994) filed a patent application on field effect transistors (1934)

Fig. 1



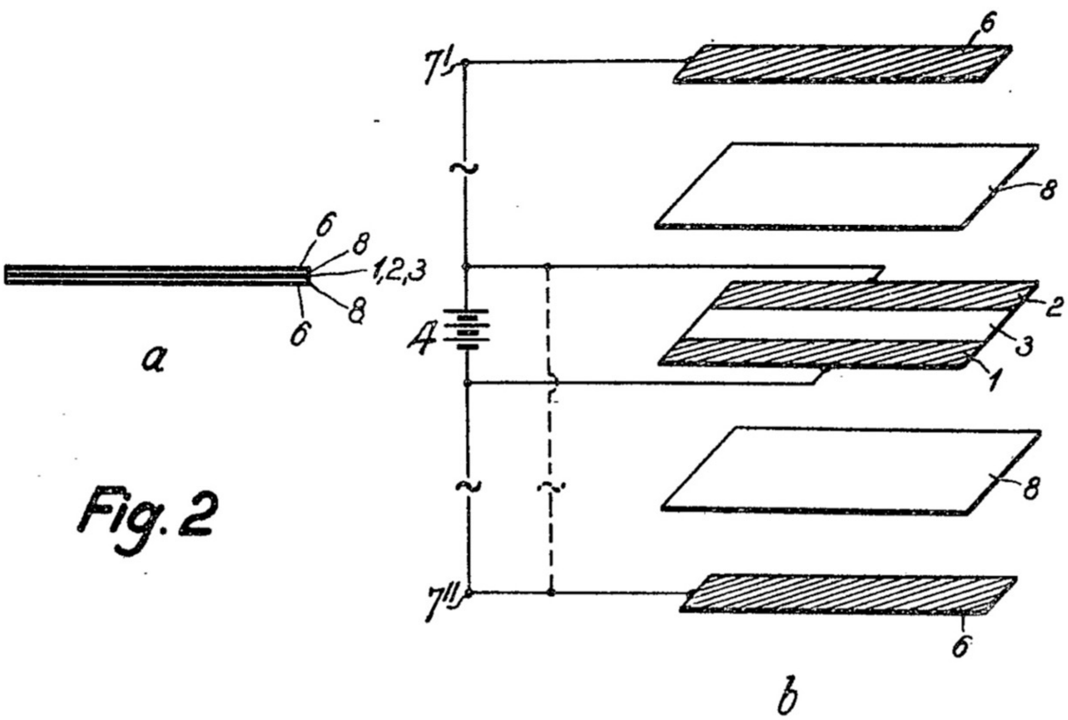


Figure 6.76: Oskar Heil filed a detailed patent application on field effect transistors in 1934.

Transistors (2)

Oskar Heil (1908–1994) filed a patent application on field effect transistors (1934)

Nr. 184396 **Klasse 112**

SCHWEIZERISCHE EIDGENOSSENSCHAFT

EIDGEN. AMT FÜR GEISTIGES EIGENTUM

PATENTSCHRIFT

Veröffentlicht am 1. August 1936

Gesuch eingereicht: 25. Februar 1935, 20 Uhr. — Patent eingetragen: 31. Mai 1936.
(Priorität: Deutschland, 2. März 1934.)

HAUPTPATENT

Dr. Oskar HEIL, Berlin-Grunewald (Deutschland).

Verfahren zum Steuern oder Verstärken elektrischer Ströme.

Die vorliegende Erfindung betrifft ein Verfahren und eine Vorrichtung zum Steuern oder Verstärken elektrischer Ströme.

Während man bisher zu diesem Zweck fast ausschließlich Elektronenröhren verwendet hat, beruht das erfindungsgemäß beanspruchte Verfahren auf einem ganz neuen Effekt, der zum ersten Mal beobachtet wurde.

Es wurde festgestellt, daß dünne Schichten von Halbleitern ihren Widerstand für den elektrischen Strom in weiten Grenzen ändern, wenn man diese Schichten als Elektroden von Kondensatoren ausbildet und die Elektroden auf verschiedene Spannung auflädt.

Zur näheren Erläuterung diene die schematische beispielsweise Darstellung in Fig. 1. Zwischen den Metallelektroden 1 und 2 befindet sich die dünne Schicht des Halbleiters 3. Die Batterie 4 schickt einen Strom durch die dünne Halbleiterschicht, der mittels Amperemeter 5 gemessen wird. Lädt man nun die Elektrode 6 positiv oder negativ gegenüber der Schicht 3 auf, so ändert sich der elektrische Widerstand dieser Schicht und damit auch die am Amperemeter 5 gemessene Stromstärke. Es ist also möglich, durch Anlegen einer irgendwie geformten Wechselspannung an die Klemmen 7 den Strom in 5 zu steuern. Mit solchen Anordnungen lassen sich in ähnlicher Weise wie mit Elektronenröhren Verstärker bauen. Es ist vorteilhaft, den Abstand zwischen der Elektrode 6 und dem Halbleiter 3 möglichst gering zu machen, etwa durch Verwendung einer dünnen Isolierschicht von weniger als $^1/_{100}$ mm Dicke zwischen beiden. Zweckmäßigerweise findet dabei ein Isoliermaterial von hoher Dielektrizitätskonstante Anwendung (mit einem Zahlenwert von 10 oder darüber).

Statt eine Steuerelektrode 6 kann man auch zwei Steuerelektroden 6 zu beiden Seiten der Schicht 3 anordnen; statt dessen können solche auch nur auf einer Seite angebracht werden. Man kann sie in diesem Falle nebeneinander oder hintereinander, bezogen auf die Stromrichtung im Halbleiter,

Figure 6.77: Oskar Heil filed a detailed patent application on field effect transistors in 1934.

Transistors (3)
Gilles Holst and Willem Christiaan van Geel filed a patent application on transistors (1935)

Patented Sept. 26, 1939 **2,173,904**

UNITED STATES PATENT OFFICE

2,173,904

ELECTRODE SYSTEM OF UNSYMMETRICAL CONDUCTIVITY

Gilles Holst and Willem Christiaan van Geel, Eindhoven, Netherlands, assignors to N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

Application March 4, 1936, Serial No. 67,052
In Germany March 9, 1935

3 Claims. (Cl. 179—171)

The invention relates to an electrode system of unsymmetrical conductivity formed by two layers of different emitting capacity which are separated from one another by a layer of insulating material.

It is known already that if cuprous oxide rectifiers form the starting point, a three-electrode system may be produced by providing in the semi-conductive oxide layer a grid to which an auxiliary voltage is applied in order to act upon the electron current flowing from the copper electrode to the semi-conductor. Experiments have shown, however, that a detector thus produced does not function satisfactorily.

Furthermore, it has previously been proposed to form a detector as a dry rectifier in which the electron current between the metallic electrode and the semi-conductor is acted upon by the field variation of a magnetic circuit of which the rectifier forms a part. This form of construction has the drawback that it takes up much room and cannot be operated in a simple manner.

The invention has for its object to provide a detector or amplifier capable of taking the place of the present valves with thermal emission which are complicated and expensive in initial cost as well as in operation, for example, due to the current consumption for heating the cathode.

According to the invention, an electrode system of unsymmetrical conductivity is formed by two layers of different emitting capacity which are separated from one another by a layer of insulating material, and embedded in the insulating intermediate layer is a grid provided with a supply conductor for applying potentials for the control of the electron current and/or for screening purposes.

A detector of this kind may consequently take the place of a usual detector or three-electrode-amplifying valve for it likewise comprises both an emitting electrode and an electrode which does not or substantially does not emit and, between these two electrodes, a grid which corresponds to a grid arranged in a valve in the vacuum between the cathode and the anode. In accordance with the invention, the grid is located in the insulating layer, which, as has been found, has the most favorable result. It is clear that the number of grids need not be limited to one.

A favorable form of execution of an electrode system according to the invention is that which follows:

The grids are constituted by perforated layers of conductive material which are contained in the insulating intermediate layer, said perforated layers being obtained, for example, by applying to one of the electrodes alternately an insulating layer and a perforated conductive layer and finally to the last conductive layer again an insulating layer. It is consequently possible to form electrode systems which correspond to the present radio valves having three or more electrodes such as, for example, the triodes, tetrodes, pentodes, hexodes, etc.

It is particularly important and advantageous that the insulating intermediate layer which contains the grids be formed independently of the adjacent electrode layers, for this renders it possible to control at will both the thickness of the layer and the position of the grids. The intermediate layer may be constituted of, for example, artificial resin which is applied in liquid condition to one of the electrodes. It is thus possible to apply a perfectly homogeneous layer.

It is of course very desirable to make the intermediate layer as thin as possible in order to raise as much as possible the electrical field strength between the main electrodes, as this has a great effect on the favorable operation. Due to the presence of a conductive grid there arises however the possibility that due to the too slight thickness of the insulating layer at a single, for example, accidentally projecting point, said grid may short-circuit one of the electrodes. In one favorable form of execution the risk of a short circuit is avoided by providing the grids with an insulating coating before they are applied to the insulating layer.

When choosing a grid material it should be considered that on account of its own emission a grid of emitting material acts upon the electron current between the anode and the cathode.

According to a favorable mode of execution use is therefore made of a grid material being a semi- or bad conductor and having a slight emitting capacity.

The invention will be explained more fully with reference to the accompanying drawing which represents, by way of example, one embodiment thereof.

The main electrodes 1 and 2 are formed, respectively, by a conductor consisting of a metal of high emitting capacity such as aluminum, copper or silver and by a semi-conductor as is usual in dry rectifiers. Selenium is a very suitable material for the semi-conductor.

The drawing represents, by way of example, a six-electrode-system. Besides the main electrodes 1 and 2 there are consequently four further

Figure 6.78: Gilles Holst and Willem Christiaan van Geel filed a patent application on transistors in 1935.

Transistors (3)

Gilles Holst and Willem Christiaan van Geel filed a patent application on transistors (1935)

2 2,173,904

electrodes (screen and control grids and the like). The main electrodes are separated from one another by means of an insulating material 3. In the example shown there are a plurality of grids which have been applied so as to alternate with the insulating layers.

In producing such an electrode system one starts, for example, with a main electrode 2 with smooth contact surface. To this electrode is applied, for example, by spraying, an insulating layer 3 to which is applied a grid 4 which is provided with a supply conductor 5 in order to apply potentials. Then an insulating layer 3' is applied again and subsequently again a grid 4' provided with a supply conductor 6. Thus one proceeds until the required number of grids is present and lastly an insulating layer is applied to the last grid.

The grids consist of perforated plates which before being applied to the insulating layers may be provided with an insulating coating. They may be constituted, for example, by a perforated and electrolytically oxidized plate of aluminum or by a perforated plate coated with a thin layer of artificial resin. Alternatively, the grids may be formed as wire gauze.

What we claim is:

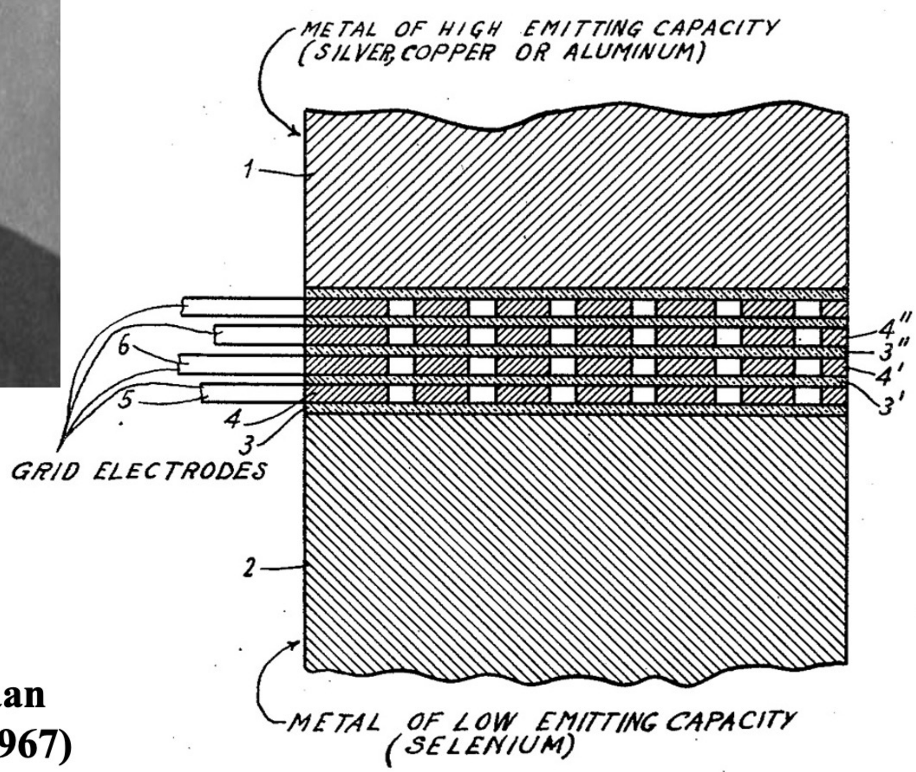
1. An electrode system for the detection or amplification of electric currents comprising a pair of main electrodes in spaced relation, one of which has a high emitting capacity and is made of a metal from the group including silver, copper and aluminum, and the other of which has a low emitting capacity and is made from selenium, a plurality of control electrodes also in spaced relation interposed between the main electrodes, and thin layers of insulating material interposed between and contacting with the surfaces of adjacent control electrodes and the surfaces of adjacent main and control electrodes.

2. An electrode system as defined in claim 1, wherein an artificial resin constitutes the layers of insulating material between the several electrodes.

3. An electrode system as defined in claim 1 wherein the control electrodes are made from aluminum, the surfaces of which have been oxidized.

GILLES HOLST.
WILLEM CHRISTIAAN VAN GEEL.

Gilles Holst (1886–1968)



Willem Christiaan van Geel (1895–1967)

Figure 6.79: Gilles Holst and Willem Christiaan van Geel filed a patent application on transistors in 1935.

Transistors (4)
Rudolf Hilsch and Robert Pohl demonstrated a proof-of-concept point-contact transistor with 20x signal amplification (1938)

Rudolf Hilsch and Robert Pohl. 1938. *Zeitschrift für Physik* 111:399.

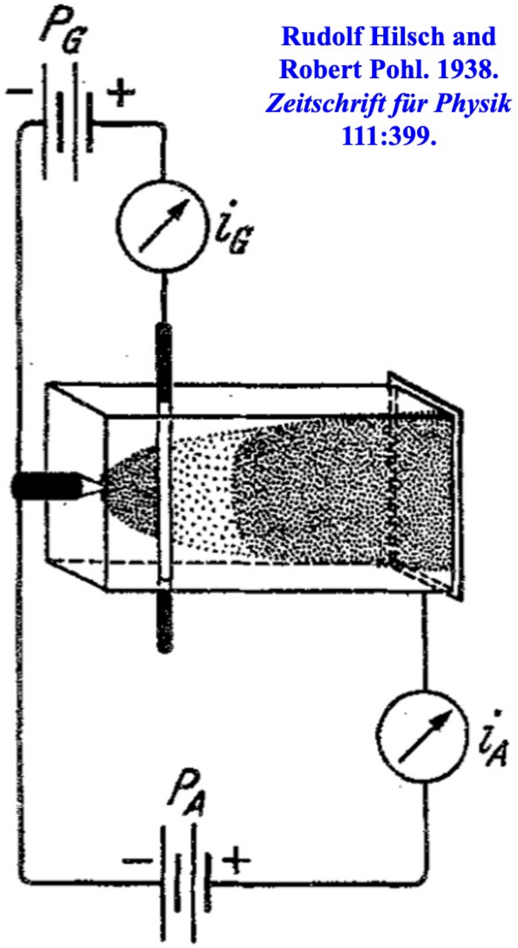


Fig. 6. Schema und Schaltung eines Dreielektrodenkristalles. Gezeichnet ist die durch Farbzentren sichtbar gemachte Elektronenverteilung während einer Abnahme des Anodenstromes. Die negative Aufladung des Gitters ist vergrößert worden, der Anodenstrom hat aber noch nicht seinen stationären Wert erreicht. (Kristallabmessungen $2 \times 5 \times 10$ mm).

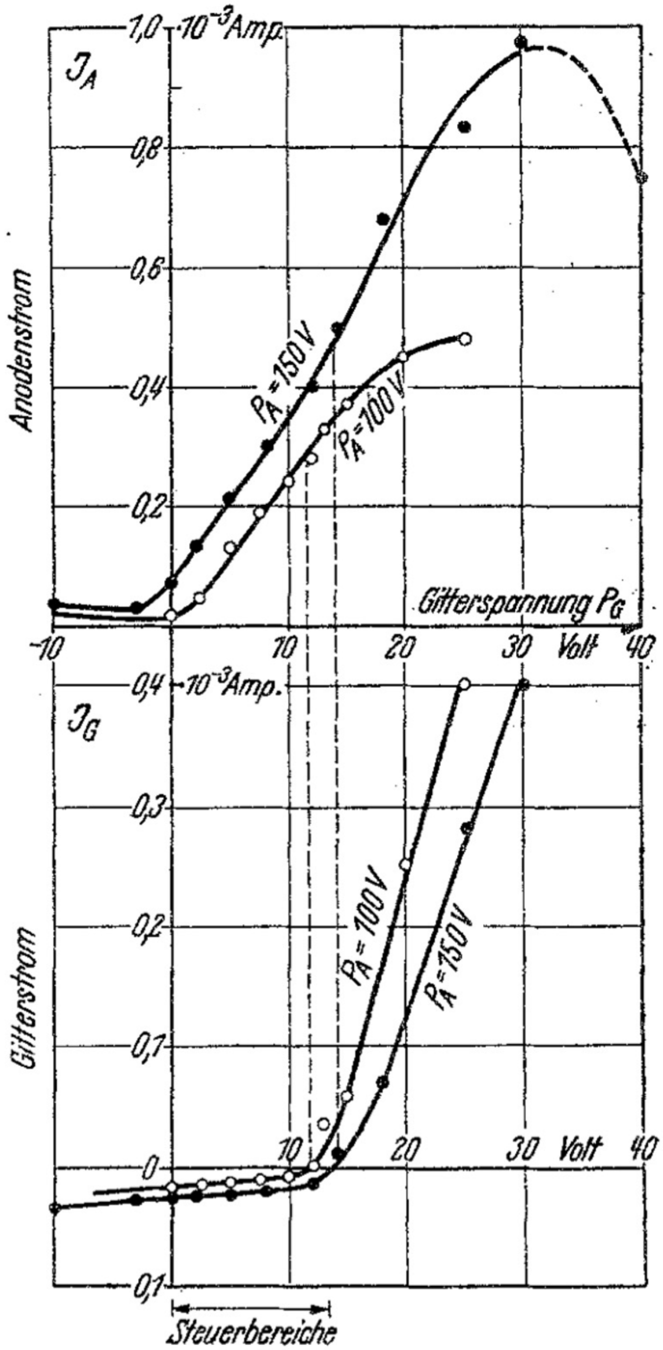


Fig. 7 und 8. Die beiden Kennlinien eines Dreielektrodenkristalles mit 20facher Verstärkung. $T = 490^0$ C.

Figure 6.80: Rudolf Hilsch and Robert Pohl demonstrated a prototype point-contact transistor in 1938 [Hilsch and Pohl 1938].

Transistors (4)

Robert Pohl (1884–1976)

Rudolf Hilsch (1903–1972)

Hilsch and Pohl demonstrated a proof-of-concept point-contact transistor with 20x signal amplification (1938).

KBr semiconductor crystal only worked at high temperature (490^{o}C) and voltages (100-150 Volts).

Hilsch proposed that the results be replicated by modifying existing room-temperature semiconductor diodes to add a third electrode for the base.

Rudolf Hilsch. 1939. Elektronenleitung in Kristallen. *Die Naturwissenschaften* 27:489-492:

"This measurement has shown for the first time that it is also possible to control currents in solid bodies. The inertia of the currents in this 'large' model is naturally large. It is now only a technical task to add the control grid in the thin barrier layers of engineering rectifiers. If the solution to this problem is successful, the three-electrode crystal can also gain technical significance alongside the three-electrode tube."

What did Hilsch and Pohl work on 1938–1945? At the very least, their 1938 paper inspired other German-speaking scientists.

Figure 6.81: Rudolf Hilsch and Robert Pohl demonstrated a prototype point-contact transistor in 1938 [Hilsch and Pohl 1938].

Transistors (5)

Erich Habann (1892–1968) filed a very detailed patent application on point-contact transistors, their fabrication, and use (1942)

Erich Habann's Hessenwinkel laboratory

Figure 6.82: Erich Habann filed a very detailed patent application on point-contact transistors, their fabrication, and use in 1942, which suggests that he had already demonstrated them at his Hessenwinkel laboratory.

Transistors (5)

Erich Habann

1942 patent application

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 971 775

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H 11624 VIII c/21g

Dr. Erich Habann, Berlin-Hessenwinkel
ist als Erfinder genannt worden

Dr. Hildegard Koepke, Berlin-Zehlendorf

Einrichtung zur Verstärkung elektrischer Ströme und Spannungen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 22. September 1942 an

Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 1951)

Patentanmeldung bekanntgemacht am 20. August 1953

Patenterteilung bekanntgemacht am 12. März 1959

Die Erfindung benutzt zur Verstärkung elektrischer Ströme oder Spannungen einen Trockengleichrichter. Dieser besteht z. B. beim Selentrockengleichrichter aus Selen in kristallisiertem Zustande als Halbleiter, das sich als dünne Schicht zwischen zwei Elektroden befindet, die bei gleicher Feldstärke als Kathoden verschieden große Elektronenströme in das Selen hineinzusenden vermögen. Je unterschiedlicher die beiden Elektroden in ihrer Emissionsfähigkeit sind, desto besser arbeitet der Gleichrichter. In der Praxis wird Selen bei so hoher Temperatur auf einer Nickelunterlage geschmolzen, daß sich zwischen dem Nickel und dem Selen eine dünne Schicht von Nickelselenid bildet. Dieses Nickelselenid vermag als Kathode nur sehr geringe Elektronenmengen in das Selen zu emittieren, im Gegensatz zu den Metallen wie Cadmium, Blei, die als Kathoden bei gleich großer Feldstärke erheblich größere Elektronenmengen in das Selen hineinzusenden vermögen. Die Metalle selbst unterscheiden sich im übrigen nur wenig in ihrem Emissionsvermögen untereinander. Eine Selenschicht, die sich zwischen einer Nickelselenidelektrode auf der einen Seite und einer Metallelektrode auf der andern Seite befindet, wird große Ströme hindurchlassen, wenn die Metallelektrode Kathode ist, und nur sehr geringe Ströme hindurchlassen, wenn die Nickelselenidelektrode Kathode ist.

Die Erfindung geht von diesen Erkenntnissen aus. Sie geht ferner von der Erkenntnis aus, daß der Strom in der Selenschicht ein reiner Elektronenstrom ist, daß dieser außer von der Elektronenemissionsfähigkeit der anliegenden Kathode von der elektrischen Feldstärke abhängt, die an dieser Kathode herrscht, und daß demgemäß die Verhältnisse ähnlich liegen wie bei Hochvakuumröhren mit Glühkathode. Infolgedessen muß sich mit dem Trockengleichrichter auch ein Verstärker analog den Glühkathoden-Verstärkerröhren zusammenbauen lassen. Da wegen der dünnen Selenschicht der an sich bekannte Einbau eines Gitters nicht zum gewünschten Ziel führt, wird die eine Elektrode erfindungsgemäß unterteilt, derart, daß der eine Teil als Steuerorgan dient und aus einem Metall besteht, das mit der Gleichrichterschicht durch chemische Reaktion eine Übergangsschicht bildet. Grundsätzlich ist es möglich, dieses Steuerorgan entweder auf der Anodenseite unterzubringen oder, wie in der Zeichnung, auf der Kathodenseite. Die beiden Elektroden *a* und *b* liegen hier in einer Ebene auf derselben Seite der Selenschicht, während auf der andern Seite der Selenschicht die Anode *A* anhaftet. *a* ist die Steuerelektrode und entspricht dem Gitter in den Verstärkerröhren, *b* ist die Emissionskathode und entspricht dem Glühfaden in Verstärkerröhren. Damit die von der Steuerelektrode ausgehenden elektrischen Kraftlinien sich möglichst zwischen Emissionskathode *b* und Steuerelektrode *a* ausbilden und weniger zwischen Steuerelektrode *a* und Anode *A*, verdient die Anordnung gemäß der Zeichnung den Vorzug vor einer Anordnung des Steuerorgans auf der Anodenseite. Außerdem werden in der Zeichnung die Steuerelektrode *a* und die Emissionskathode *b* in Streifen rasterartig ineinandergeschachtelt, wobei möglichst keiner der Streifen breiter gehalten wird, als die Selenschicht dick ist. Die Streifen *a* werden unter sich elektrisch verbunden, und ebenso sind die Streifen *b* unter sich elektrisch verbunden. Die Streifen sind durch dünne Isolationsblättchen (Glimmer) voneinander gegen seitliche Berührung isoliert. Die Anode *A* stellt in üblicher Weise eine zusammenhängende Fläche aus einem aufgespritzten oder angepreßten Metall dar.

Die Verstärkung hängt hauptsächlich von dem Verhältnis der Oberflächen der Streifen der Emissionskathode zu denen des Steuerorgans ab. Natürlich kommen die Oberflächen nur so weit in Betracht, als die Emissionskathode und die Steuerelektrode die Selenschicht tatsächlich berühren. Das Verhältnis spielt eine ähnliche Rolle wie der Durchgriff bei Verstärkerröhren: je kleiner das angegebene Verhältnis ist, desto größer ist der Verstärkungsgrad. Die Schaltung ist der der Verstärkerröhren analog: Der zu verstärkende Strom wird zwischen Emissionskathode *b* und Steuerelektrode *a* gelegt. Der verstärkte Strom wird zwischen Emissionskathode *b* und Anode *A* abgenommen. Zwischen der Kathode *b* und der Anode *A* liegt ständig eine entsprechend bemessene Gleichspannung, und zwar mit dem negativen Pol an der Emissionskathode *b* und mit dem positiven Pol an der Anode *A*. Die Steuerelektrode *a* muß eine negative Gleichspannung vorgespannt erhalten, ähnlich der negativen Vorspannung der Gitter bei Verstärkerröhren. Diese Gleichspannung — ebenfalls optimal bemessen — liegt also mit dem negativen Pol an der Steuerelektrode *a* und mit dem positiven Pol an der Emissionskathode *b*.

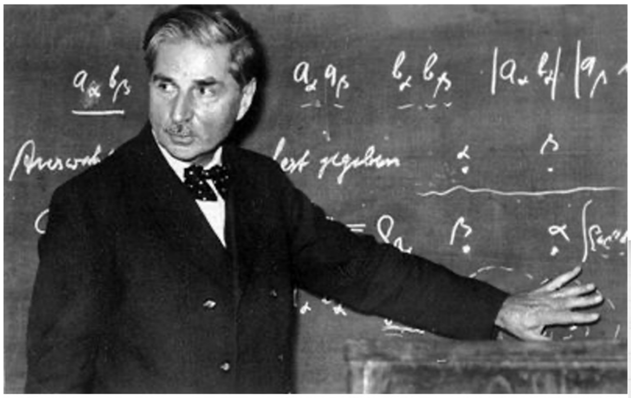
Eine solche Einrichtung würde auf der Steuerseite noch zuviel Energie verbrauchen, als Verstärker also noch wenig oder gar nicht funktionieren. Die Steuerelektrode *a* wird nun aus einem Material angefertigt, das möglichst schlecht Elektronen in die Gleichrichterschicht (Se) emittiert, z. B. Nickelselenid, während die Emissionskathode *b* aus einem Material hergestellt wird, das möglichst gut und reichlich Elektronen in die Gleichrichterschicht emittiert (praktisch alle Metalle). Unter den hier möglichen Metallen kommen besonders diejenigen in Betracht, die sich nicht mit Selen verbinden. Dies sind außer Graphit Chrom und Aluminium. Das Material der Anode ist gleichgültig. Zweckmäßig besteht es aus Blei oder Cadmium oder Zinn oder einer leicht aufspritzbaren Metallegierung.

Der Raster wird aus entsprechend geschnittenen Streifen, aus dünnem Nickelblech für die Steuerelektrode *a* und aus dünnen Aluminiumfolien für die Emissionskatode *b*, gebildet. Die der Selenschicht zugekehrte Fläche der Streifen wird möglichst eben gemacht. Auf ihr wird Selen in etwa $^1/_{10}$ bis $^2/_{10}$ mm dicker Schicht zum Schmelzen gebracht. Die Fläche mit der Selenschicht wird dann so hoch erhitzt, bis das Nickel mit dem Selen reagiert und eine oberflächliche Nickelselenidschicht bildet, aber nicht so hoch erhitzt, daß auch das Aluminium reagiert (300° C genügen). Die Erhitzung erfolgt so lange, bis sich die Nickeloberfläche vollständig mit der Nickelselenidschicht von ausreicher Dicke bedeckt hat. Darauf wird die Schicht bei 200° C oder besser durch Abschrecken zum Erstarren gebracht. Dann wird zweckmäßig mit einem Graphit- oder Aluminiumstempel die Selenschicht fest an ihre gerasterte Unterlage gepreßt und mehrere Stunden unter diesem Preßdruck bei etwa 120° C und dann bei 210° C angelassen. Schließlich wird auf die fertige und abgekühlte Schicht nach Entfernung des Druckstempels eine leicht schmelzende Metallegierung, z. B. aus Cadmium und Zinn, als Anode *A* aufgespritzt oder auch nur eine Bleiplatte als Anode *A* gegen die Selenschicht gepreßt. Für die Selenschicht ist eine bestimmte Dicke optimal. Ist sie zu dick, so spielen die Unterschiede in der Elektronenemissionsfähigkeit der anliegenden Elektroden nicht mehr die entscheidende Rolle. Der Strom wird dann hauptsächlich von der Eigenleitfähigkeit des Selens bestimmt. Bei zu dünner Schicht leidet die Durch-

Figure 6.83: Erich Habann filed a very detailed patent application on point-contact transistors, their fabrication, and use in 1942, which suggests that he had already demonstrated them at his Hessenwinkel laboratory.

Transistors (6)

Walter Schottky (1886–1976) published detailed analyses of semiconductor properties necessary for transistors. The U.S. seized all his papers in 1945 and never returned them.



(Mitteilung aus der Zentralabteilung der Siemens & Halske A.-G., Berlin-Siemensstadt.)

Vereinfachte und erweiterte Theorie der Randschichtgleichrichter.

Von **W. Schottky.**

Mit 14 Abbildungen. (Eingegangen am 27. September 1941.)

1. Die Schicht konstanter Raumladungsdichte. 2. Die allgemeine Strom-Spannungsbeziehung bei Gleichstrom. 3. Verhalten in Sperr- und Flußrichtung. 4. Vergleich mit der strengen Theorie. 5. Die Schicht konstanter Raumladungsdichte bei Wechselstrom. 6. Kapazitätsbeobachtungen an Selengleichrichtern. 7. Zur Frage des Gleichstromverhaltens von Selengleichrichtern. 8. Beobachtete und berechnete Kennlinien von Selengleichrichtern. 9. Bildkraft-Wirkungen bei Selengleichrichtern. 10. Wirkungen der diskreten Raumladungsverteilung in der Randschicht. 11. Verhältnisse bei unvollständiger Störstellendissoziation. 12. Anwendung auf den Kupferoxydulgleichrichter. (Zusammenfassung am Schluß.)

Das genauere Studium der Kupferoxydul- und Selengleichrichter [1]) hat zu der Erkenntnis geführt, daß bei diesen beiden Gleichrichteranordnungen, die bisher als die technisch wichtigsten anzusehen sind, eine völlige Ionisierung der (Defekt-)Elektronen abgebenden Störstellen in einer etwa 10^{-5} cm dicken, unmittelbar an das Gleichrichtermetall angrenzenden Schicht des Halbleiters anzunehmen ist. Ferner hat sich herausgestellt, daß das Gleich- und Wechselstromverhalten dieser Gleichrichter ganz überwiegend durch die Eigenschaften dieser „Erschöpfungsrandschicht" („Durchführung", S. 235) bestimmt ist, während die Schichten, in denen eine unvollkommene Ionisierung der Störstellen oder eine teilweise Kompensation der Störstellenladungen durch (Defekt-)Elektronenladungen vorhanden sind, nur eine geringe Rolle spielen.

Diese Erkenntnis ist nicht nur von physikalischem und technischem Interesse, sondern ermöglicht auch eine stark vereinfachte mathematische Darstellung der für diesen Gleichrichtertyp maßgebenden Erscheinungen;

[1]) W. Schottky u. E. Spenke, Zur quantitativen Durchführung der Raumladungs- und Randschichttheorie der Kristallgleichrichter, Wiss. Veröff. Siemens-Werke **18**, 225, 1399; im folgenden zitiert als „Durchführung"; W. Schottky, Abweichung vom Ohmschen Gesetz in Halbleitern, Phys. ZS. **41**, 570, 1940; W. Schottky, Über Sperrschichten, Schweizer Archiv für angewandte Wissenschaft u. Technik, **7**, 20—29 u. 82—86, 1941, im folgenden zitiert als „Archiv"; Annemarie Schmidt, Messungen an Selengleichrichtern und Sperrschichtzellen, ZS. f. Phys. **117**, 754, 1941.

DECLASSIFIED
Authority NND 968018

February 19, 1947

Dear Mr. Webb,

this is to confirm a telephone discussion with you of today on the matter of additional data on Selenium Rectifier developments in Germany.

Up to now the following reports on German developments have been released in USA:

PB-67, PB-423, PB-425, PB-916, PB-18781, PB-21981, PB-25662 and PB-32591.

All of these reports discuss the methods and problems of SAF; ~~one~~ report only, namely PB-18781 (by H. Dauber), discusses certain aspects of AEG and Siemens work on rectifiers and one, namely PB-25662, gives some comparison between AEG and SAF rectifiers.

Thus of the three selenium rectifier manufacturers in Germany, two — AEG and Siemens — have not been overexploited.

There were three research centers on Selenium rectifiers in Germany: at Darmstadt headed by Dr. Brill and H. Krebbs, ~~at~~ in Prague headed by Prof. Gudden and the third of the Siemens Co headed by Dr. Schottky.

A complete summary of the Darmstadt group has been obtained and reported by me and Col Range.

A good summary of the Prague group has been given by Harry Dauber in his report on a basis of a large file of documents and data removed from Gudden's laboratory in Prague. But no trace yet has been found of Dr. Schottky's files removed from him by some officers early in 1945.

be sent to you in Washington where it might be rearanged and appraised by an expert from one of the rectifier manufacturers.

(c) That a very strong attemp be made both here and in Great Britain to locate Dr. Schottky's files. In USA it might be in the hands of the Air Intelligence at Wright Field, or in Pentagon, or in the hands of the Signal Corps Labs in New-Jersey, or else in the hands of the US Navy in Washington. Perhaps a letter to the Intelligence Branches of the Army + the Navy might start the machinery going.

Yours [illegible]

Zeitschrift für Physik **118:9–10:539–592 (1942)**

NARA RG 40, Entry UD-75, Box 24, Folder Selenium Rectifier Machinery

Figure 6.84: Walter Schottky published detailed analyses of semiconductor properties necessary for transistors in 1942. All of his papers were seized by the United States in 1945 and never returned.

Transistors (6)

Walter Schottky

PATENTSCHRIFT

Nr. 841 174

KLASSE 21g GRUPPE 11 02

p 11610 VIIIc/21g D

Dr. Walter Schottky, Pretzfeld (OFr.)
ist als Erfinder genannt worden

Siemens & Halske Aktiengesellschaft, Berlin und München

Halbleiteranordnung

Patentiert im Gebiet der Bundesrepublik Deutschland vom 2. Oktober 1948 an

Patentanmeldung bekanntgemacht am 21. Dezember 1950

Patenterteilung bekanntgemacht am 24. April 1952

Es sind Anordnungen bekanntgeworden, bei denen ein Störstellenhalbleiter (Germanium) von beispielsweise flachzylindrischer Form so mit Elektroden versehen wird, daß die Grundfläche mit einer großen, im folgenden als *O*-Elektrode bezeichneten Metallelektrode im Kontakt ist, während auf der oberen Fläche eine Metallspitze mit positivem Potential von etwa 1 V gegen die *O*-Elektrode als Steuerelektrode, im folgenden als *G* bezeichnet, dient und eine etwa $^1/_{10}$ mm davon entfernt aufgesetzte Spitze, im folgenden mit *B* bezeichnet, den zu beeinflussenden Strom nach der *O*-Elektrode abführt; die *B*-Elektrode hat hierbei ein negatives Potential von etwa 10 V gegen die *O*-Elektrode.

Die Steuerwirkung derartiger Anordnungen beruht darauf, daß die *G*-Elektrode bei den gewählten Betriebsspannungen einen durch kleine Änderungen von U_g stark variierenden Strom von Defektelektronen in den Halbleiter entsendet, wobei dieser Halbleiter infolge eines gewissen Zusatzes von Elektronen abgebenden Störstellen als Überschußhalbleiter wirkt. Die *B*-Elektrode, die als Kathode gegenüber der *O*-Elektrode geschaltet ist, stößt die Überschußelektroden des Halbleiters ab und vermag, solange kein *G*-Strom fließt, nur dadurch einen Strom zu führen, daß Elektronen aus *B* in den Halbleiter entsendet werden, was bei dem gewählten Halbleiter bedeutend höhere Spannungen erfordert als in umgekehrter Richtung zur Emission von Defektelektronen notwendig sind. Da unter diesen Bedingungen die Elektronenemission von der an der *B*-Elektrode herrschenden Feldstärke abhängt, ist es möglich, diesen Elektronenstrom dadurch zu beeinflussen, daß die von *G* kommenden Defektelektronen teilweise zur Elektrode *B* abfließen; bei den großen Absolutstromdichten, von der Größenordnung 100 A/cm², um die es sich dabei handelt, bilden die nach *B* abfließenden Defektelektronen in den unmittelbar an *B* angrenzenden Schichten des Halbleiters eine positive Raumladung aus, die in der bekanntgewordenen Anordnung anscheinend noch dadurch verstärkt wird, daß in einer dünnen die obere Fläche des Halbleiters bedeckenden Schicht Defektelektronen abgebende Störstellen eingebaut sind, die im Betriebszustand weitgehend ihrer Defektelektronen beraubt sind (Erschöpfungsrandschicht) und infolgedessen die von *G* durch den Halbleiter nach *B* gelangenden Defektelektronen zu binden vermögen, so daß im Effekt die Defektelektronen zu längerem Aufenthalt im Randgebiet vor *B* gezwungen und somit in ihrer felderhöhenden Raumladungswirkung unterstützt werden.

In Erkenntnis dieser in der Literatur bisher nicht beschriebenen Wirkungsweise der an sich bekannten Anordnungen, in denen übrigens die Rolle der Überschuß- und Defektelektronen bei geeigneter anderer Wahl der Störstellen und evtl. des Grundmaterials sowie der Spannungen vertauscht werden kann, erscheint es als Idealziel, das Eindringen der Defektelektronen in die *B*-Elektrode, das deren Raumladungswirksamkeit gewissermaßen vorzeitig beendet, ganz zu vermeiden und die Defektelektronen so lange in der vor *B* wirksamen Raumladungskathodenschicht des Halbleiters verweilen zu lassen, bis sie durch Wiedervereinigung mit den diese Schicht passierenden Elektronen, ihr unvermeidliches und natürliches Ende finden. In dieser Richtung bieten sich im Rahmen der bekannten Anordnung gewisse Möglichkeiten, indem man die Defektelektronen abgebende Störstellenschicht vor der *B*-Elektrode genügend breit macht und die Ablösungsarbeit der Defektelektronen von ihren neutralen Störstellen genügend groß, so daß eine durch das starke Randfeld ihres Defektelektrons beraubte und dann durch ein aus dem Halbleiter kommendes Defektelektron wieder neutralisierte Störstelle ihre neutrale Ladung genügend lange behält, ehe sie durch thermische Anregung in Form eines abgespaltenen Defektelektrons wieder negativ aufgeladen wird.

Doch sind diesen Retardierungsmethoden der auf die *B*-Elektrode zuströmenden positiven Ladungsteilchen gewisse Schranken gesetzt. Erfindungsgemäß wird nun, alternativ oder in Kombination mit der Störstellenretardierung ein anderes Mittel angewandt, um die aus *G* kommenden Defektelektronen am Eindringen in die *B*-Elektrode zu verhindern und sie so lange in der vor *B* ausgebildeten Raumladungsrandschicht zurückzuhalten, bis sie durch Wiedervereinigung mit den aus *B* kommenden Überschußelektronen ihr natürliches Ende gefunden haben. Dieses Mittel besteht darin, daß man die Elektrode *B* nicht in direkte Berührung mit dem benutzten Halbleiter, der im folgenden als Grundkristall *Gr* bezeichnet wird, bringt, sondern zwischen Grundkristall und *B*-Elektrode eine vorzugsweise 10^{-5} bis 10^{-4} cm dicke Schicht eines anderen kristallinen Stoffes mit besonderen Eigenschaften, im folgenden als Fremdschicht *F* bezeichnet, zwischengeschaltet.

Um die erfindungsgemäß verlangten Eigenschaften und die Wirkungsweise dieser Fremdschicht zu erläutern, sind in Fig. 1 die Energieniveaus für Überschuß- und Defektelektronen für zwei störstellenfreie, einander unmittelbar berührende verschiedenartige Kristalle dargestellt, wie sie gemäß der Erfindung für die Fremdschicht und den Grundkristall vorgeschrieben werden.

E_- bedeutet das Energieniveau, das ein überschüssig in den Kristall eingebrachtes Elektron im Ruhezustand einnehmen würde, E_+ das Energieniveau, das ein von außen eingebrachtes Elektron vorfindet, wenn es sich an den Ort einer ruhenden im Grundgitter des betreffenden Kristalls vorhandenen Elektronenlücke einbaut. (Im Rahmen der wellenmechanischen Vorstellungen bedeutet E_- den unteren Rand des tiefsten elektronenfreien Energiebandes, E_+ den oberen Rand des höchsten noch mit Elektronen voll besetzten Energiebandes). Der Niveauunterschied zwischen E_- und E_+ innerhalb jedes Kristalls bedeutet den Energieaufwand, um im ungestörten Kristall ein Elektron aus seinem normalen gebundenen Zustand in den freien beweglichen Zustand zu bringen, wobei gleichzeitig eine Elektronenlücke (Defektelektron) und ein Überschußelektron entsteht. Dieser Energieunterschied wird deshalb im folgenden als Elektronenpaarbildungsarbeit oder kurz als Paarbildungsarbeit bezeichnet. Die relative Lage von E_- bzw. E_+ in den beiden aneinandergrenzenden Kristallen kann, außer von den verschiedenen chemisch und strukturell bedingten Kräften, mit denen die Elektronen im E_- bzw. E_+ Niveau der beiden Kristalle gebunden sind, noch von etwaigen molekularen elektrischen Doppelschichten an der Kristallgrenze abhängen, ist aber bei reinen Substanzen und reinen Oberflächen sowie gegebenenfalls festgelegter Kristallorientierung eine eindeutige Eigenschaft der beiden Kristalle.

Erfindungsgemäß wird nun für den Grundkristall eine Substanz mit kleiner Paarbildungsarbeit gewählt, wie z. B. *Ge*, während die Fremdschicht eine mindestens um mehrere Zehntel *eV* größere Paarbildungsarbeit aufweisen soll, z. B. *Si*. Ferner soll E_+ im Grundkristall mindestens einige Zehntel *eV* oberhalb des E_+-Niveaus in der Fremdschicht liegen, während E_- im Grundkristall entweder unterhalb oder nur knapp oberhalb des E_--Niveaus in der Fremdschicht liegen soll. Da, wie durch die Pfeile in Fig. 1 angedeutet, die mit − bezeichneten Überschußelektronen jeweils das niedrigere Energieniveau zu erreichen streben, besteht unter den Verhältnissen von Fig. 1 keine Hemmung für den Übergang der Überschußelektronen aus der Fremdschicht in den Grundkristall. Dagegen bedeutet der Übergang einer Elektronenlücke, d. h. eines Defektelektrons +, von unten nach oben den Übergang eines Elektrons von oben nach unten;

Figure 6.85: Walter Schottky published detailed analyses of semiconductor properties necessary for transistors in 1942. All of his papers were seized by the United States in 1945 and never returned.

Detailed patent application based on wartime work filed 6 April 1945

Transistors (7)
Heinrich Welker & Herbert Mataré

980 084

Patentschrift 980 084

Aktenzeichen:	P 98 00 84.4-33 (F 7622)
Anmeldetag:	~~11. August 1955~~ 6. 4. 1945
Offenlegungstag:	—
Auslegetag:	—
Ausgabetag:	2. August 1973
Beginn des Patents:	7. April 1945

Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet (Ges. v. 15. 7. 1951)

Bezeichnung:	Halbleiteranordnung zur kapazitiven Steuerung von Strömen in einem Halbleiterkristall
Zusatz zu:	—
Ausscheidung aus:	—
Patentiert für:	Siemens AG, 1000 Berlin und 8000 München; Telefunken GmbH, 1000 Berlin; Standard Elektrik Lorenz AG, 7000 Stuttgart
Vertreter gem. § 16 PatG:	—
Als Erfinder benannt:	Welker, Heinrich, Prof. Dr. habil., 8520 Erlangen

1

Patentansprüche:

1. Halbleiteranordnung mit einem Halbleiterkristall, der mit zwei stromführenden Elektroden kontaktiert und außerdem mit einer Steuerelektrode versehen ist, welche den zwischen den beiden stromführenden Elektroden im Halbleiterkristall im wesentlichen parallel zur Fläche der Steuerelektrode fließenden elektrischen Strom kapazitiv steuert, **dadurch gekennzeichnet,** daß zwischen dem stromführenden Halbleiterkristall und der ebenfalls als Halbleiterkristall ausgebildeten Steuerelektrode eine elektronische Sperrschicht (Verarmungsrandschicht) erzeugt ist.

2. Halbleiteranordnung nach Anspruch 1, dadurch gekennzeichnet, daß die Kristallite der Halbleiterkörper so groß sind, daß eine etwaige weitere Auskristallisation den Widerstand des gesamten Halbleiters nicht mehr verändert.

3. Halbleiteranordnung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß ein elektronenleitender Halbleiterkristall durch einen defektelektronenleitenden Halbleiterkristall gesteuert ist.

4. Halbleiteranordnung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß ein defektelektronenleitender Halbleiterkristall durch einen elektronenleitenden Halbleiterkristall gesteuert ist.

5. Halbleiteranordnung nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß zusätzlich zu dem äußeren Feld der Steuerelektrode noch innere Felder vorgesehen sind, die von geordneten atomaren oder molekularen Schichten ausgehen.

6. Halbleiteranordnung nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß die Halbleiter aus Silicium oder Germanium bestehen.

7. Halbleiteranordnung nach einem der Ansprüche 1 bis 6, dadurch gekennzeichnet, daß die Halbleiter aus CU_2O, Se, PbS oder ZnS bestehen.

8. Halbleiteranordnung nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß an der Steuerelektrode ein Spannungsabfall aufrechterhalten ist.

9. Halbleiteranordnung nach einem der Ansprüche 1 bis 8, dadurch gekennzeichnet, daß die Stromelektroden auf die Halbleiterkristalle sperrschichtfrei aufgebracht sind.

10. Halbleiteranordnung nach einem der Ansprüche 1 bis 9, dadurch gekennzeichnet, daß der stromführende Halbleiterkristall auf eine elektrisch isolierende Trägerplatte möglichst hoher Wärmeleitfähigkeit aufgebracht ist.

Bei Untersuchungen über die Wanderung von Farbzentren in einem Alkalihalogenidkristall, die von R. W. Pohl in den Nachr. von der Ges. d. Wiss. zu Göttingen, Jahresber. 1933/34, S. 55, beschrieben sind, ist der Gedanke geäußert worden, die Elektronenröhren in den Rundfunkgeräten durch kleine Kristalle zu ersetzen. Zu einem mo-

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dellmäßigen Versuch über die Steuerung von Elektronen in Kristallen kam es jedoch erst mehrere Jahre später, als man die Bedeutung der Sperrschichten für die Gleichrichtung erkannt hatte. Es ist damals vorgeschlagen worden, in die Sperrschicht eines Alkalihalogenidkristalls ein Steuergitter einzubauen; vgl. hierzu R. Hilsch und R.W. Pohl, Z.S.Phys., 111, 399, 1938. Die Sperrschicht ist hier der glasklare, an eine Elektrode grenzende Teil des sonst mit Farbzentren erfüllten Kristalls. Sie ist bei diesen Versuchen von makroskopischen Abmessungen, und der zu steuernde Strom durchfließt dabei die Sperrschicht senkrecht, oder genauer gesagt, er fließt im wesentlichen parallel zur Dickenausdehnung der Sperrschicht. Im allgemeinen ist die Trägheit der mit Alkalihalogenidkristallen arbeitenden Anordnung ungeheuer groß, und ein stationärer Zustand stellt sich überhaupt nicht ein. Aus diesen Gründen haben die genannten Versuche nicht zu einem technisch brauchbaren Gleichrichter oder gar Verstärker geführt.

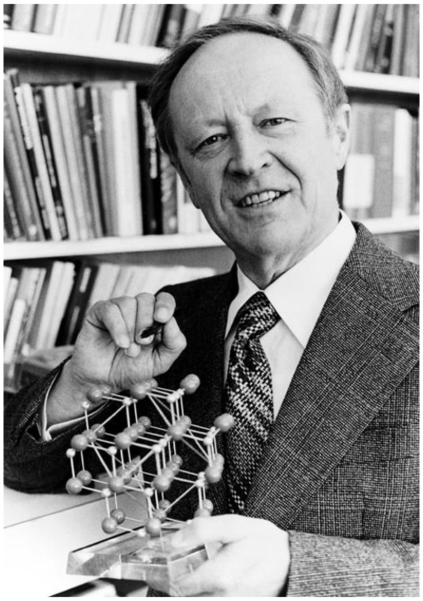
Ganz anders liegen die Verhältnisse bei den technischen Gleichrichtern (Selen- u. Kupferoxydulgleichrichter, Spitzendetektor). Die hier auftretenden Sperrschichten sind nicht wie die glasklaren Sperrschichten bei den Alkalihalogenidkristallen elektrisch neutral, sondern besitzen eine merkliche, mit der äußeren elektrischen Spannung veränderliche elektrische Raumladung. Zur Erläuterung des Sachverhaltes wird festgestellt, daß bei obigen Versuchen außer den beweglichen Elektronen (gewöhnliche Elektronen oder die neuerdings viel diskutierten Defektelektronen) gleichzeitig auch bewegliche Ionen vorhanden sind. Eine Sperrschicht entsteht in diesem Falle dadurch, daß sowohl die Elektronen als auch die Ionen aus dem fraglichen Gebiet herauswandern. Die Bewegung erfolgt so, daß nirgends ein Überschuß an Ladung auftritt; es treten daher auch keine rücktreibenden Kräfte auf; die Dicke der Sperrschicht kann daher unbegrenzt wachsen. Bei den technischen Gleichrichtern hingegen ist die Ionenbeweglichkeit vernachlässigbar klein. Das Herauswandern der Elektronen aus einem Randgebiet führt notwendig zur elektrischen Aufladung dieses Gebietes. Die dabei auftretenden rücktreibenden Kräfte verhindern, daß die Sperrschichten beliebig dick werden. Neuerdings, vergleiche hierzu W. Schottky: Über Sperrschichten, Schweizer Archiv, 1941, Heft 1 und 3, insbesondere S. 29 oben rechts und Anmerkung 13, hat man die Dicke dieser Sperrschichten, die wir zur Unterscheidung von den Sperrschichten bei Alkalihalogenidkristallen elektronische Sperrschichten nennen wollen, zu 10^{-5} cm abgeschätzt und auch aufgeklärt, weshalb gerade bei den technisch brauchbaren Kristallgleichrichtern der Einbau eines Steuergitters in die Sperrschicht und damit der Bau eines Kristallverstärkers auf rein elektronischer Grundlage unmöglich ist.

Heil beschreibt in der britischen Patentschrift 439 457 eine Anordnung, bei der die nach dem geschilderten Stand der Technik sich darbietenden Schwierigkeiten teilweise vermieden werden. Bei dieser bekannten Anordnung werden in Kristallen unter der Wirkung eines elektrischen Steuerfeldes elektronische Randschichten erzeugt und verändert, und der zu steuernde Strom wird senkrecht zur

Figure 6.86: Heinrich Welker and Herbert Mataré began developing a point-contact transistor in Germany during the war, filed a detailed patent application based on that wartime work on 6 April 1945, and publicly announced their transistor in 1948 in France.

Transistors (7)

Heinrich Welker
(1912–1981)



Herbert Mataré
(1912–2011)

Patented Mar. 30, 1954 **2,673,948**

UNITED STATES PATENT OFFICE

2,673,948

CRYSTAL DEVICE FOR CONTROLLING ELECTRIC CURRENTS BY MEANS OF A SOLID SEMICONDUCTOR

Herbert François Mataré and Heinrich Welker, Vaucresson, France, assignors to Societe Anonyme dite: Compagnie des Freins et Signaux Westinghouse, Paris, France

Application August 11, 1949, Serial No. 109,752

Claims priority, application France August 13, 1948

3 Claims. (Cl. 317—235)

1

This invention relates to crystal devices for controlling electric currents by means of a solid semiconductor with the use of one or more control electrodes, either in a barrier layer of the semiconductor (see for example patent of addition No. 38,744 of July 5, 1930, to French Patent No. 649,432 of January 28, 1928, and French Patent No. 866,372 of October 5, 1942), or closely adjacent to semiconductive layers with a suitable insulator interposed therebetween (see French Patent No. 786,454 of March 1, 1935).

However, such systems were so difficult to apply on a commercial scale that they had to be abandoned or development had to be restricted to simple experimental models or laboratory samples. This experience is supported by publications such as: Nachrichten der Gesellschaft der Wissenschaften zu Göttingen, Yearly Report, by R. W. Pohl, 1933/34, page 55; Schweizer Archive, 1941, volumes 1 and 3: Ueber Sperrschichten, by W. Schottky; Zeitschrift fur Physik, vol. 111, volumes 5 and 6, 1938 (R. Hilsch and R. W. Pohl); Modern Theory of Solids, 1940 (F. Seitz); Crystal Rectifiers, 1948 (H. C. Torrey and C. A. Whitmer).

In order practically to carry into effect systems comprising solid semiconductors arranged to produce electronic relay effects similar to those occurring in electronic tubes, two essential difficulties must be overcome. Firstly, the diameter of the contact area between metal needle and crystal should be of an order proportional to the thickness of the crystal barrier layer. Secondly, the gap between the conductive electrodes where engagement occurs with the semiconductor should be so selected that one of the conductive electrode point members will be positioned inside the barrier layer area of the other point member.

With the thickest barrier layer made hitherto, it would have been necessary to use values lower than 5 μ both for the diameters of the contact areas, on the one hand, and for the gap be-

2

or n-type excess and p-type deficiency concentration, respectively, that the inner resistivity of the device becomes very high. Arrangements of this type cannot be used practically for technical purposes.

The present invention permits to eliminate the above-mentioned difficulties and to realize on a commercial scale multi-electrode crystal devices of this kind for producing electronic relay action.

A more specific object of this invention is a multi-electrode device with at least two semiconductors of different conductivity characteristics; one of the semiconductors forms a control electrode and includes a surface barrier layer.

According to another feature of the invention, one of the semiconductors preferably the control electrode has a p-type (deficiency) or non-electronic conductivity and the other semiconductor an n-type (excess) or electronic conductivity.

According to a further feature of the invention, a semiconductor, preferably the other semiconductor mentioned above also includes a surface or internal barrier layer.

In one embodiment of the invention, the semiconductors or electrodes of the crystal are formed simultaneously from a single semiconductive element (such as germanium). In this element, by any suitable known method, zones of different conductivity characteristics are created.

Still in accordance with the invention, in at least one of said semiconductors or in one of the zones thereof such geometrical configuration is provided as to assure substantial radial distribution of the lines of force of the electric fields.

Furthermore, the invention relates to novel commercial products comprising multi-electrode crystal devices wherein external conductive electrodes are in direct contact with each semiconductive electrode, and wherein there is a gap between the contact points which is greater than 50 μ.

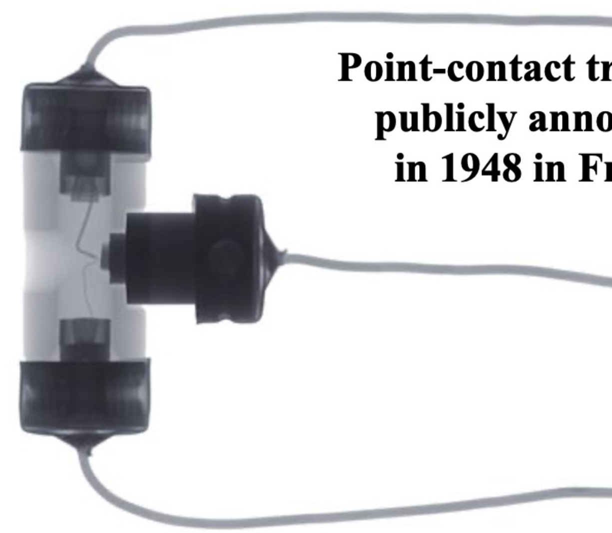


Figure 6.87: Heinrich Welker and Herbert Mataré began developing a point-contact transistor in Germany during the war, filed a detailed patent application based on that wartime work on 6 April 1945, and publicly announced their transistor in 1948 in France.

Transistors (8)

Erwin Weise (19??–19??) described a transistor to Allied investigators

CIOS XXXI-2

1. Target No.

2.3. Laboratory of the Technical High School, Berlin, evacuated to Bad Liebenstein. Person interrogated: Dipl.Ing. Erwin Weise, formerly of Osram, now attached to this laboratory.

4. Interview only. Ovens and vacuum equipment for experimental work are in workable condition.

5. (1) Semi-conducting materials such as titanium-titanium dioxide resistors.
   (11) Investigation of very thin films of titanium dioxide (TiO_2)
   (111) Practical applications involving the use of these thin films:-
   - a. Pyrometers.
   - b. Gas pressure and flow devices.
   - c. Rapid acting simulated pendulum.

   (1V) Electrically controlled friction devices for control and amplification of mechanical forces.

6. Laboratory subject to guard regulations of 8th Corps Area. A book was just being written on the subject of semi-conductors by Mr. Weise, and it is desirable to obtain a copy when available.

7. Priority.

8. Mr. Weise spoke disparagingly of Dr. Pearson's published works on semi-conductors (Bell Laboratories). He was scheduled to lecture in America on this subject prior to the war at the request of Western Electrical Instrument Co., Irvington, NY. Claims to be a friend of Henry Behring of this company.

9. 5th June 1945.

10. Investigators: Mr. C.W. Hansell
    Lt. Col. J.J. Slattery
    Maj. J.M. Sanabria
    Pfc. F. Koppl

11. Documents removed: "Uber ein Messgerät für hohe und niedrige Gasdrucke mit Halbleiterwiderstanden" by Erwin Weise. Zeitschr.f. techn. Physik, No.4 1943, pages 66 to 69. No reports were available at the time but Mr. Weise stated that a manuscript of his should be produced within thirty days, and it is suggested that this matter be further investigated.

With the development of the new titanium dioxide semi-conductors this old abandoned development has been revived with much more promising results, because of the relative perfection, uniformity and hardness of the new materials. It has been suggested by Mr. Weise and others that electrically controlled friction clutches may very well assume considerable importance in the future.

In general the clutches provide control of mechanical power by electrical power in a manner to give very great amplification and rapid response. For many applications they might replace the Amplidyne or Metadyne control devices which are now in use on a large scale in military equipment and in industry.

THERMAL ELECTROMOTIVE FORCE OF TiO_2 SEMI-CONDUCTORS

Mr. Weise said that titanium dioxide types of semi-conductors had been found to provide thermal electromotive forces about ten times greater than that of metals and that this might lead to important applications.

ELECTRONIC AMPLIFIERS WITHOUT VACUUM.

According to Mr. Weise he had some ideas and had demonstrated the possibility of using thin films or control electrodes in semi-conducting materials to provide control of current flow similar to the control of current flow in high vacuum tubes. This work had not approached a stage where practical applications might be made.

Figure 6.88: Erwin Weise told Allied investigators that he "had demonstrated the possibility of using thin films or control electrodes in semi-conducting materials to provide control of current flow similar to the control of current flow in high vacuum tubes" to create "electronic amplifiers without vacuum."

Transistors (8)

B.I.O.S. FINAL REPORT No. 1658 (Interrogation Report No. 600)

ITEM No. 9

Erwin Weise (19??–19??) described a transistor to Allied investigators

INTERROGATION OF ERWIN WEISE

Research and Development of Semi-Conducting Materials

Practical Applications for Ultra-Sensitive Temperature Measuring Equipment and Automatic Control and Stabilizing Problems

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.

BIOS 1658

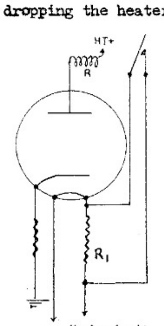
All the above publications were written by Weise either alone or in collaboration with another.

The following patents relate to inventions made by Weise:

DRP. 607 444 Carrier with two records of oscillations in one trace
" 618 982 Control resistor to diminish the starting time of cathodes
" 632 820 Network for the quick starting of cathodes in discharge tubes
" 641 680 Pipe-shaped high frequency furnace.
" 696 463 Manufacture of very thin semi-conductors.
" 697 174 Resistors of semi-conducting materials.
" 701 478 Electrical measurement of low gas and steam pressures
" 716 052 Equipment for fitting very thin semi-conductors
" 721 677 Stabiliser for D.C. and A.C. voltages.
" 730 251 Equipment for fitting very thin semi-conductors.
" 743 780 Measurements of the velocity of gases, slight changes in air pressure, and altitudes of aircraft.
" 743 575 Network to raise the slope of the characteristics of electron tubes.
Secret 1 Use of resistance controller as an amplifier and generator of slow electrical oscillations.
Secret 2 Instrument for measuring the inclination of ships, incorporating semi-conductors of little inertia.

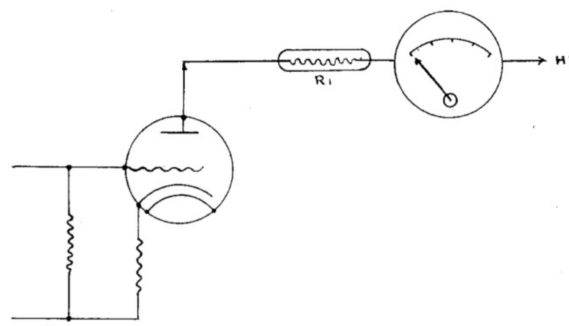
I questioned Weise as to details of some of these patents and obtained the following explanations:-

DRP 618 982. This patent relates to method of accelerating the warming up of indirectly heated cathodes. A voltage of some two or three times the working voltage of the heater is applied. The relay R at this stage is resting on its back contacts thereby short circuiting R_1. As soon as anode current commences R operates leaving R_1 in series thereby dropping the heater voltage to its normal value.



Remarks. Exact details may not be quite as above, but will serve to illustrate the principle which no doubt is capable of considerable refinement. The system might be applied as a hot wire microphone in Sound Ranging if not already entirely superseded by the Moving Coil type.

DRP. 743 575. Where it is desired to raise the slope of a thermionic valve a resistor of high value made of semi-conductor material is placed in the anode lead as under:



Any increase in anode current brought about variation of grid volts will raise the temperature of R_1 thereby lowering its resistance and bringing about a larger increase in anode current per unit change in grid volts than would have otherwise been the case.

Remarks. Only applicable where grid voltage changes are fairly slow such as in a Valve Voltmeter. Correction for ambient temperature may be obtained if required by connecting a suitable metallic resistor in series with R_1 although there is no material the exact counterpart of the semi-conducting material it is possible by careful selection of values to obtain almost exact compensation over a fairly useful range.

Secret 1. This application appears to be somewhat of an extension of the idea in the previous patent. By evolving a suitable valve/resistance/capacity network using semi-conductor resistors and their negative temperature/resistance characteristics it is possible to produce very slow and regular oscillations.

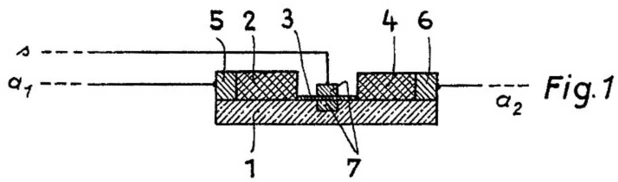
Remarks. Weise was unable to remember exact details of the circuit. It was not clear what the Germans proposed to use this for and as it was getting late the matter was not pursued further.

Figure 6.89: Erwin Weise told Allied investigators that he "had demonstrated the possibility of using thin films or control electrodes in semi-conducting materials to provide control of current flow similar to the control of current flow in high vacuum tubes" to create "electronic amplifiers without vacuum."

Transistors (9)

Frank Rose (19??–19??)	Erich Waldkötter (19??–19??)	Eberhard Spenke (1905–1992)

Filed detailed patent applications on transistors in 1949 (based on wartime work?)



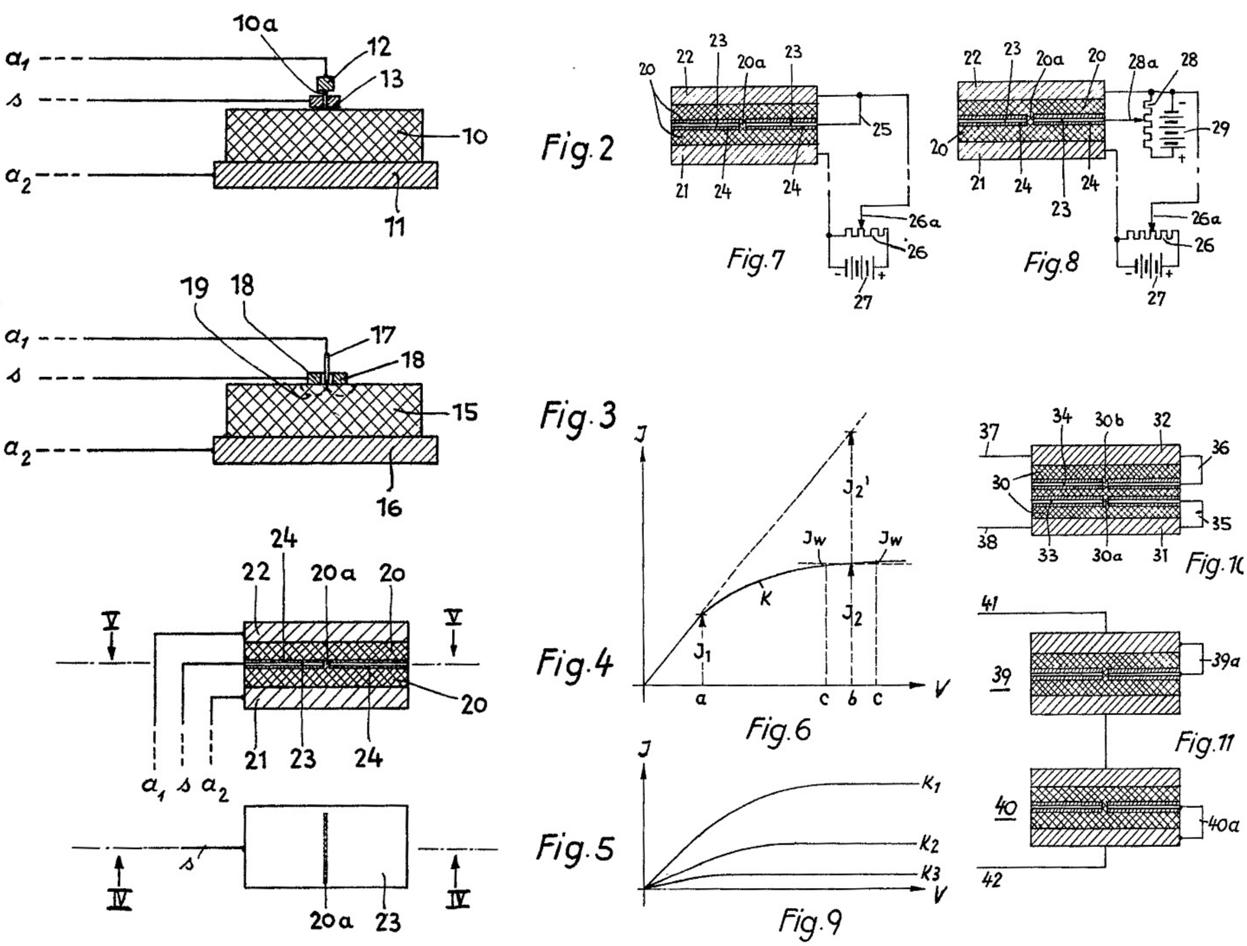


Figure 6.90: Frank Rose, Eberhard Spenke, and Erich Waldkötter filed detailed patent applications on transistors in 1949, likely based on wartime work.

Transistors (9)

Eberhard Spenke, Frank Rose, and Erich Waldkötter filed detailed patent applications on transistors in 1949 (based on wartime work?)

Nr. 285603 Nr. 285603

SCHWEIZERISCHE EIDGENOSSENSCHAFT

EIDGENÖSSISCHES AMT FÜR GEISTIGES EIGENTUM

PATENTSCHRIFT

Veröffentlicht am 5. Januar 1953 Klasse 112

Gesuch eingereicht: 30. Mai 1950, 18 Uhr. — Patent eingetragen: 15. September 1952.
(Prioritäten: Deutschland, 30. Mai, 24. und 27. Oktober 1949.)

HAUPTPATENT

Siemens-Schuckertwerke Aktiengesellschaft, Berlin und Erlangen (Deutschland)

Anordnung mit mindestens einem Widerstandselement, dessen Widerstand von wenigstens einer Steuerspannung abhängt.

Gegenstand der Erfindung ist eine Anordnung mit mindestens einem Widerstandselement, dessen Widerstand von wenigstens einer Steuerspannung abhängt.

Die Erfindung nützt jene Erscheinung aus, die man — insbesondere bei Halbleitern, wie z. B. Selen — als Sperrschichtbildung bezeichnet. Bei Halbleitern und bei verschiedenen andern Stoffen treten, wie seit langem bekannt ist, an denjenigen Stellen, die mit einem geeigneten Metall kontaktiert sind, sogenannte Sperrschichten auf, das heißt Schichten, die in ihrem Auftreten und in der Stärke von der Größe der angelegten Spannung abhängig sind und für den Stromdurchgang einen großen Widerstand bilden. Dieses Verhalten wird z. B. bei den sogenannten Trockengleichrichtern ausgenutzt, bei denen eine dünne Halbleiterschicht auf der einen Seite sperrfrei kontaktiert ist, während sie auf der andern Seite mit einer sperrschichtbildenden Belegung, der Sperrelektrode, versehen ist. Die Wirkungsweise solcher Gleichrichter ist bekanntlich die, daß sich bei Anlegung einer Spannung in der einen Richtung eine Sperrschicht ausbildet, die den Stromdurchgang in dieser Richtung praktisch sperrt, das heißt den Strom in dieser Richtung sehr klein sein läßt. Es ist nun beobachtet worden, daß die Dicke der sich ausbildenden Sperrschicht von der Größe der angelegten Spannung abhängig ist. Bei wachsender Spannung dehnt sich die Schicht hohen Widerstandes, das heißt die Sperrschicht, weiter in den Halbleiter oder den sonstigen, den Sperrschichteffekt aufweisenden Stoff hinein aus. Die von der Sperrschicht unberührt bleibende Schicht des Stoffes wird also um die Schichtstärke der Sperrschicht kleiner. Bei der Anordnung nach der vorliegenden Erfindung ist diese Erscheinung ausgenutzt; und zwar dadurch, daß erfindungsgemäß wenigstens ein Strompfad des Widerstandselementes in einem Halbleiter verläuft und von einer Sperrschicht eingegrenzt ist, die eine Blende für den Strom bildet, deren Öffnungsweite von der Steuerspannung abhängig ist (Sperrschichtblende).

Die Erfindung betrifft ferner ein Verfahren zur Herstellung einer besonderen Ausführungsform dieser Anordnung. Dieses Verfahren wird an Hand der Fig. 4 beispielsweise erläutert werden.

Es bestehen verschiedene Möglichkeiten für den Aufbau einer solchen Anordnung. Zum Beispiel kann der Widerstand aus einem mit zwei Anschlußelektroden versehenen Halbleiterkörper gebildet werden, während die in seinem Strompfad liegende Sperrschichtblende durch eine Stelle starker Zusammendrängung der Strombahnen und durch eine an dieser Stelle angebrachte Sperrelektrode gebildet wird. Diese Zusammendrängung der Strombahnen läßt sich durch entsprechende Formgebung des Halbleiterkörpers herbeifüh-

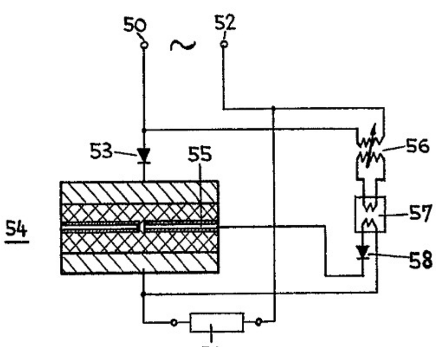


Fig. 12

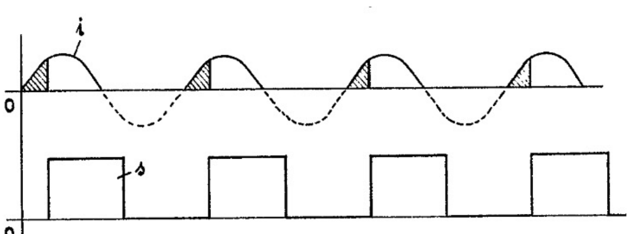


Fig. 13

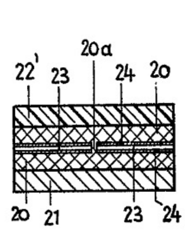


Fig. 14

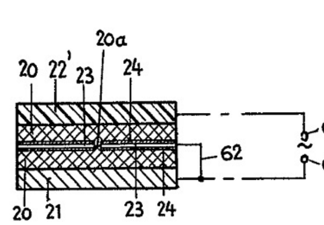


Fig. 15

Figure 6.91: Frank Rose, Eberhard Spenke, and Erich Waldkötter filed detailed patent applications on transistors in 1949, likely based on wartime work.

Transistors (10)

Design and fabrication of silicon semiconductor devices (wartime onward)

COMBINED INTELLIGENCE OBJECTIVES SUBCOMMITTEE
EVALUATION REPORT 350 (28 August 1945)

INTERVIEW AT HEIDENHEIM WITH PROF. DR. PAUL GUNTHER,
UNIVERSITY AND HOCHSCHULE OF BRESLAU,
ON SILICON CRYSTALS
(Target No. C-22/1326)

Prof. Gunther's work was done in the Hochschule at Breslau under the direction of Major Rossler of the Germany Air Corps research organization. The crystals were used as detectors in ultra high frequency equipment.

According to his theory, the main difficulty with silicon crystals has been impurity. In general, the technique is the same as reported from interrogations of Dr. Bartels at Heidelberg and Dr. H. Rothe (Telefunken) at Dachau, but is reported here as received.

The carbon used was supplied by Siemens-Plania of Berlin, as "homogeneous" carbon made into rods 1.5 mm. in diameter and 6 mm. long from graphite powder. The rods are washed in nitric acid and piled like cordwood in a try within a tube so that only the two ends are coated with silicon to a thickness of .01 mm. and then broken in two making two detector units. In the same tube, about 12" long and 1.5" diameter is a vessel h very pure aluminum pellets. The cube is placed in a vacuum system and within an electric oven. At the far end of the system from the vacuum pump is a bulb of Si Cl4 kept in a cold container. Between the bute and the pump is a liquid air trap to keep Si Cl4 from reaching the pump and a mercury type shut-off valve.

In operation the oven is heated to 750°C and the system evacuated for ten to twenty minutes. When the pressure is down to 10^{-4} mm. and the Si Cl4 has purged the system of air, the temperature is held at between 720° and 950° for three to six hours. The temperature of the Si Cl4 normally rises from -20°C to -15°C and the pressure of the system is 40.mm. of mercury. The conditions give a super-saturated vapor of silicon which condenses on the carbon. The aluminum chloride apparently remains in the aluminum container although according to Dr. Bartels it condenses on the tube and acts as an indicator of the reaction.

Dr. Gunther disclaims knowledge of the mounting of these crystals and their electrical characteristics, but thinks molybdenum wire contacts were used. Dr. Zeiler, also at Breslau Hochschule, worked on that problem. Nevertheless, he stated the best samples could stand up to 30 volts and the average worked well at 15 volts. At the "Nullpunkt widerstandt" the resistance was 50 ohms and at the "Bandwiderstandt" 30 ohms, the current ratios at these two points being 1:200. The crystals were considered good if when the voltage was 100 millivolts, the ratio of forward to reverse current was greater than five.

Gunther had also worked on Fe S_2 as a detector but found crystals of it variable. He had commenced an investigation to determine whether their detector action at high frequency breaks down because of chemical or physical changes.

Gunther was interested in work done at Munich by Heinrich Welker under Clusus on Germanium crystals. Using similar reactions and technique to those he had used with silicon, Gunther had found that the dual conductivity of the resulting crystals was caused by the presence of up to 20% of aluminum in the crystals. When he succeeded in getting good crystals, they were good detectors with resistances ranging from 15,000 to 20,000 ohms. The good crystals were obtained by exposing GE Cl_4 to a stream of H_2 at 700°C.

There seemed to be some evasiveness on the part of Dr. Gunther because when there were questions concerning the growing of quartz crystals, he did not mention the work of E. J. Chytrek of Breslau, one of his students who was experimenting with growing quartz crystals in a solution of sodium carbonate.

28 July 1945

R. H. McCarthy
J. R. Townsend
P. Mertz
Consultants

All from AT&T Bell

CIOS ER 350

Paul Ludwig Günther (1892–1969)

Karl Seiler (1910–1991)

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
28. SEPTEMBER 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 891 426

KLASSE 21g GRUPPE 11 02

T 5268 VIIIc / 21g

Dr. phil. habil. Karl Seiler, Klein Kreidel bei Methne
ist als Erfinder genannt worden

Telefunken Gesellschaft für drahtlose Telegraphie m. b. H., Berlin

Hochfrequenz-Kristalldetektor

Patentiert im Gebiet der Bundesrepublik Deutschland vom 16. August 1944 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 4. Dezember 1952
Patenterteilung bekanntgemacht am 20. August 1953

Figure 6.92: Karl Seiler and Paul Ludwig Günther developed methods for designing and fabricating silicon semiconductor devices throughout the war and into the postwar period.

Transistors (10)

Paul Ludwig Günther (1892–1969)

Karl Seiler (1910–1991)

United States Patent Office

2,701,216
Patented Feb. 1, 1955

1

2,701,216

METHOD OF MAKING SURFACE-TYPE AND POINT-TYPE RECTIFIERS AND CRYSTAL-AMPLIFIER LAYERS FROM ELEMENTS

Karl Seiler, Nurnberg, Germany, assignor to International Standard Electric Corporation, New York, N. Y., a corporation of Delaware

Application April 5, 1950, Serial No. 154,064

Claims priority, application Germany April 6, 1949

4 Claims. (Cl. 117—106)

Unlike the large variety of point-type rectifiers (crystal diodes) there are only a few combinations of metals and semiconductors which exhibit a surface-type rectifying effect. Schottky's analysis of semiconductor rectification (see f. i. Zeitschrift für Physik, vol. 118, 1942, pp. 539–592) sets forth several reasons which may serve to clarify this fact.

(1) The relative impurity concentration throughout the semiconductor should be a minimum in the zone of increased resistance immediately adjacent the metallic electrode, in order to avoid short-circuits. Any increase in the number of impurities in this zone means great probability of short-circuits due to so-called by-passes.

(2) In the adjacent semi-conducting zone, however, adequate conductivity has to be provided by lattice-disturbing (impurity) atoms sufficient in number to greatly accentuate the zone mentioned in paragraph (1) where the so-called borderline effects take place.

To fulfil this requirement the disassociation level of the impurity atoms should be low (the impurity atoms should not diffuse readily), while the mobility of the electric carriers should be high. That only a few surface-type rectifications effects have been realized so far, derives from the fact that these two demands have not, or have hardly, been possible of fulfilment so far, for the known methods of making specified layer patterns are based exclusively on such processes where the space distribution of the impurities, is only obtained by modifications introduced by a secondary process by removing impurities at a suitable temperature, by chemical reaction (f. i. dissolving, lacquer-layers applied later on, etc.). Hence in making some specified layer pattern, the substances intended to produce the desired effects are placed at their respective locations in a first operation where no attention can be paid as to obtaining any specified space distribution of impurities, while that specified distribution, essential for proper performance, is brought about only subsequently in a second process governed by laws different from those of the first one. Thus one has been forced to simply accept as given whatever impurity concentration and distribution resulted from that second process without the possibility of introducing such corrective action of one's own as might be desirable to secure optimum distribution of impurities across the layer. With regard to the fact that very delicate arrangements are involved with layers present only as extremely thin films, it is obvious that the probability of inadequate results is rather large if these two essential processes are practiced one after the other.

In rectifiers involving compound-type semiconductors (in particular cuprous oxide) this fact is particularly pronounced as here the change in impurity concentration is caused by a chemical reaction which in turn is to introduce the stoichiometric unbalance of the semiconductor compound.

Generally a high impurity concentration is provided in the zones of the semiconductor more remote from the metallic electrode. But a certain maximum impurity concentration should not be exceeded in the zone of the semiconductor immediately adjacent the metallic electrode. This means that along the main direction of current flow the impurity concentration will have to obey a specified functional law, i. e. the dependence of the impurity concentration at a particular layer level will depend on the distance between that layer and the metallic

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electrode. This distance, however, is extremely small so it is obvious that rather erratic results are liable to occur in the few processes available for controlling the impurity concentration.

The drawbacks of the known methods are avoided in this invention by providing that the ultimate structure of the layer pattern is no longer obtained from two independent individual processes, but that the basic and the impurity substances are deposited simultaneously on the provided foundation, and that the specified relative impurity concentration is controlled to fit the needs of each particular layer while the layer is being built, so the desired space distribution of impurities is brought about.

It is known that the elements boron, silicon, germanium, and tellurium have semiconducting properties. In view of the delicacy of the processes to be controlled, the degree of chemical purity of the substances coated on the foundation electrode is of outstanding importance in making rectifiers.

In order to achieve uniform results and to control the porportion of the impurity admixture, it might seem desirable to vaporize the semiconductor materials and the impurity substances and deposit them from the vaporous state onto a suitable foundation. However, due to the high vaporizing temperatures of the materials involved there is induced the hazards of chemical reactions of the basic material or even the impurity contents with the material of the crucible which would produce uncontrolled and undesirable effects on the rectifying properties.

In order to avoid such high temperatures in production, one starts out in the known way from a liquid compound of the elements involved which by chemical rectification and customary chemical purifying methods can be prepared with a very high degree of purity and which in turn may be reduced chemically under proper conditions upon reaction with some equally pure reducing agent. Simultaneously with this reduction, the impurity substance may be treated in the same manner. With the relatively ample choice present in selecting admixtures to semiconducting elements, there is usually found some suitable chemical reaction mechanism which enables simultaneously synthesizing the impurity admixture. In a functional schematic, the nature of the process to be adopted is indicated in Fig. 1. A, B, C, and D refer schematically to devices where the substances needed for assembling the rectifying layer are obtained in their purest form by available processes according to what has been described above. As indicated schematically, these substances are then fed through pipes L_a, L_b, L_c, and L_d to the device E where the layer pattern is formed. In Fig. 1, these pipes L_a and L_b directly feed the device E with no prior intermixing of the substances being possible. Of course, one, two, or even all of the pipes could be joined in a common duct whenever intermixing of the substances is desired or permissible at such a relatively early stage of the production process. Equally in a schematic manner are shown control mechanisms R_a, R_b, R_c, and R_d at some arbitrary point along the ducts which allow any desired decrease or increase in the feeding rate of any of the ingredients while the semiconducting system is being built up. It is by no means essential that these controlling devices be inserted somewhere between the units A and E, B and E, etc., these controlling facilities may as well be incorporated straight in the units A, B, C, D or any additional units that might be present. Care will have to be taken, however, to prevent undesired reactions on the other devices B, C, D whenever at the junction of the pipes or individual pipe ducts the gas or vapor rate of device A is increased.

To practice this method, the elements boron, silicon, germanium, or tellurium may be used because of the high mobility of their electric carriers. To provide optimum efficiency, the impurity concentration at the back or counterelectrode is chosen large enough to prevent virtually any barrier layer from forming there.

As an example of the preparation of the semiconducting substance in building of a layer pattern, silicon may be reduced with hydrogen from silicon, tetrachloride or with zinc, in order to obtain pure silicon.

It is also known that the elements which are left and

United States Patent Office

2,876,400
Patented Mar. 3, 1959

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2,876,400

COMPOSITE ELECTRODES FOR DIRECTIONAL CRYSTAL DEVICES

Paul Günther and Franz Kerkhoff, Munich, Germany, assignors to Siemens & Halske Aktiengesellschaft, Munich, Germany, a corporation of Germany

Application February 1, 1954, Serial No. 407,196

Claims priority, application Germany February 27, 1953

11 Claims. (Cl. 317—235)

This invention is concerned with composite electrodes for directional devices comprising semi-conductors, for example, transistors and the like.

Composite electrodes for the purpose and of the type noted above are generally known. It is likewise known to form on such electrodes preferably point-shaped or knife-edge contacts of a hard core which is provided with a coating of another generally softer material, the latter being more suitable than the core material to form electrical contact engagement with a semi-conductor crystal. Such a known electrode may, for example comprise a tungsten wire plated with platinum. The drawback of such structure is that it is impossible to provide upon tungsten a sufficiently uniform platinum coating and that it is consequently impossible to produce such electrodes with the required uniformity in the course of customary mass production processes.

It has been found by research lying in back of the invention that the above mentioned drawbacks can be avoided by using other particular materials. In accordance with the invention, electrodes of the previously indicated type which comprise at least two different materials, for example, a core or carrier and a coating, are made of metals from the first, fourth, fifth and/or eight groups of the periodic table of elements. More specifically a hard material as for example niobium, tantalum, iron or alloys of such materials, for example, hard bronze of the type of phosphor-beryllium-bronze or the like may be used primarily for the core of the electrode; and for the coating may be used primarily materials of high output capacity, for example, rhodium, palladium, iridium, also platinum or, under some circumstances alloys of these materials. In the case of using in a transistor a plurality of electrodes, for example, two or three electrodes, the selection of the material for the surface coating will depend upon whether the electrode is to be employed as a collector or an emitter.

The invention will now be described with reference to the accompanying drawings showing in diagrammatic representation examples thereof. In these drawings,

Fig. 1 shows a germanium crystal coacting with a single point contact electrode; and

Fig. 2 illustrates a transistor comprising a germanium crystal coacting with two point contact electrodes.

In Fig. 1, numeral **1** indicates the germanium crystal. In contact engagement with the surface of the crystal is a point electrode comprising a wire **2** of phosphor-beryllium-bronze provided with a platinum coating **3**. The electrode is produced by providing upon the bronze wire, for example, in an alkaline ammonia phosphorous platinum bath of platinum coating in galvanic manner.

Fig. 2 shows a transistor comprising a germanium crystal **4** coacting with two point contact electrodes **5**

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and **6**. Between the electrodes, a p-n layer is provided in a known manner. The electrode **5** is made like the electrode of Fig. 1, comprising a bronze core with a platinum coating **3**. The other electrode **6** comprises a steel core **7** covered by a copper coating **8**.

The coatings may be applied or provided in different manner than galvanic, for example, by vaporization, by cathode vaporization, or in mechanical manner, for example, by spraying or rolling. Burning such as is usually applied in the production of mirrors, ceramics, etc., is recommended for mass production.

What is believed to be new and desired to have protected is defined in the appended claims.

We claim:

1. A transistor comprising a crystal, in electrode in point contact with said crystal, said electrode including a core and a coating surrounding said core, said core formed from one or more metals of the group consisting of niobium, tantalum, iron, copper, tin, zinc, phosphorous, beryllium and alloys of the aforesaid metals, said coating formed from one or more metals of the group consisting of rhodium, palladium, iridium, platinum and alloys of the aforesaid metals, and said coating of said electrode in point contact with said crystal.

2. A transistor according to claim 1, wherein said core of the electrode comprises a hard bronze of the type of phosphor-beryllium-bronze.

3. A transistor according to claim 1, wherein said core of the electrode is formed of a hard bronze of the type of phosphor-beryllium-bronze, and said coating is formed of platinum.

4. A transistor comprising a crystal, at least two electrodes in point contact with said crystal, p-n layer provided in said crystal between the electrodes, one of said electrodes comprising a phosphor-beryllium-bronze core and a platinum coating, the other of said electrodes comprising a steel core and a copper coating, and said coatings of said electrodes in point contact with said crystal.

5. A composite electrode for a directional crystal device, said electrode provided with a point at one end for point contact with a crystal and comprising a core and a coating surrounding said core, said core formed from one or more materials of the group consisting of tantalum, phosphor-beryllium-bronze and steel, said coating formed from one or more materials of the group consisting of the elements of group eight of the periodic table of elements and consisting of rhodium, palladium, iridium and platinum.

6. A composite electrode according to claim 5, wherein said composite electrode may be used in a diode.

7. A composite electrode according to claim 5, wherein said composite electrode may be used as an emitter in a transistor.

8. A composite electrode for a directional crystal device said electrode formed with a point at one end for point contact with a crystal and comprising a steel core and a copper coating surrounding said core.

9. A composite electrode for use as a collector, said electrode comprising a core and a coating surrounding said core, said core formed from one or more materials of the group consisting of tantalum, phosphor-beryllium-bronze and steel, and said coating comprising one or more materials of the group consisting of copper and tin.

10. A semi-conductor device of the transistor type including a directional crystal, a composite electrode for point contact with said directional crystal, said composite electrode comprising a phosphor beryllium-bronze

Figure 6.93: Karl Seiler and Paul Ludwig Günther developed methods for designing and fabricating silicon semiconductor devices throughout the war and into the postwar period.

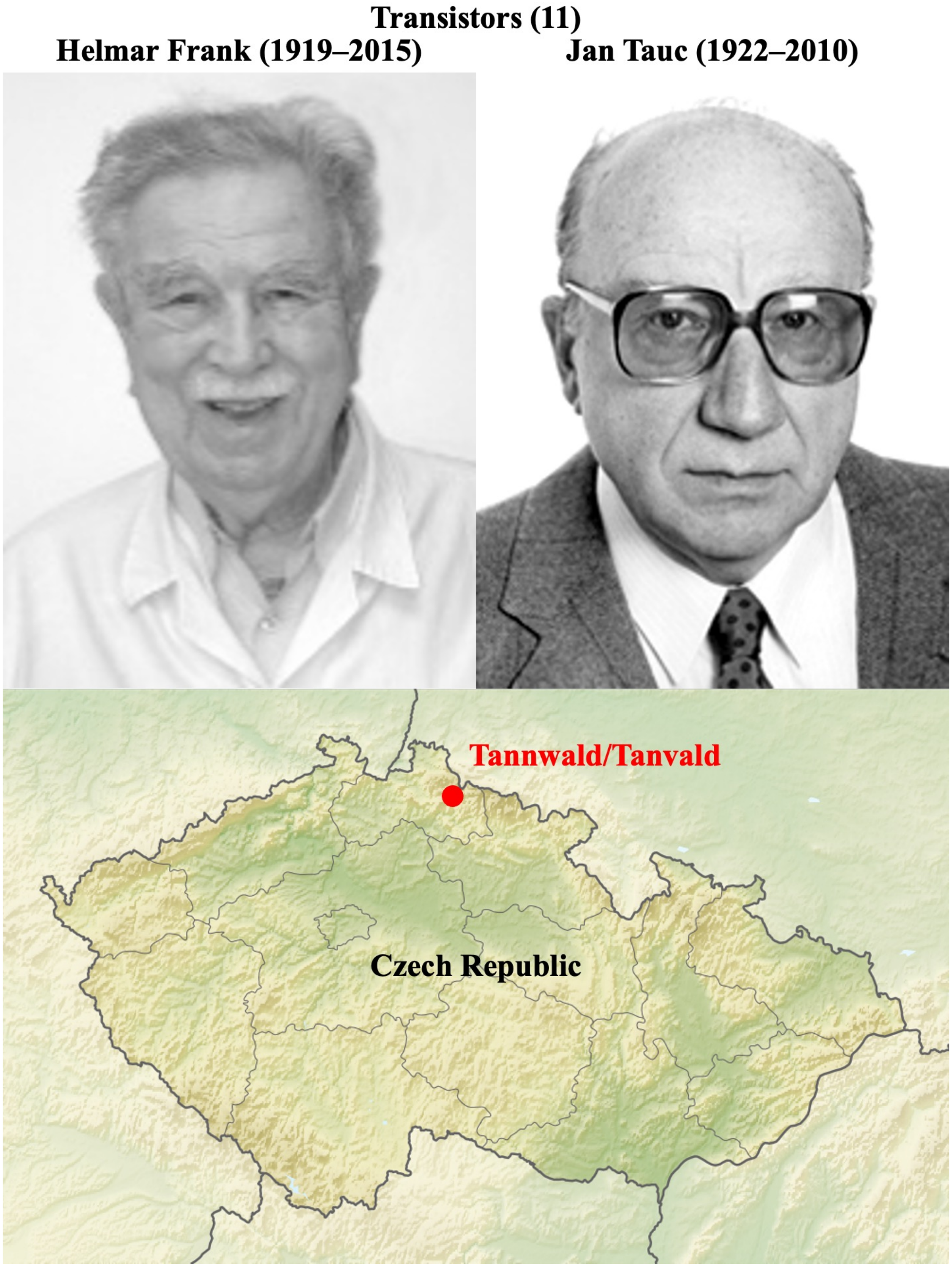


Figure 6.94: Helmar Frank and Jan Tauc produced transistors at the former German electronics laboratory in Tannwald/Tanvald in Czechoslovakia in 1949, based at least in part (and perhaps entirely) on wartime German work there.

Transistors (11) **Helmar Frank and Jan Tauc**

Bo Lojek. 2007. *History of Semiconductor Engineering.* pp. 195-204.

German military research maintained two research groups working on semiconductors in occupied Czechoslovakian "Böhmen und Mähren" territory: The Prague group headed by Prof. B. Gudden worked on the rectifying diode; a second and larger group worked in the small town of Tanvald in the North of Bohemia on microwave point contact diode and radar research. Many members of the German research groups, including Prof. Gudden, were killed in May 1945 during the liberation of Czechoslovakia by the Red Army. A major part of the Tanvald research facility was confiscated by the Soviet army and transferred to the Soviet Union; the rest of the inventory was set on fire and destroyed. Several kilograms of Germanium survived the fire and were used by Jan Tauc and Helmar Frank to build the first European [Czech] transistors in 1949. Jan Tauc later immigrated to the United States. Helmar Frank, who was also a student of Prof. Gudden at Charles University, directed post-war semiconductor research sponsored by the Czechoslovakian Army at the former Philips Laboratories in Prague. [...] At the end of the war, the CIA and KGB quickly joined the British effort and transferred several researchers from the Prague and Tanvald research groups to their respective countries.

Czech National Library of Technology. Professor Helmar Frank.
https://www.techlib.cz/cs/84002-profesor-helmar-frank

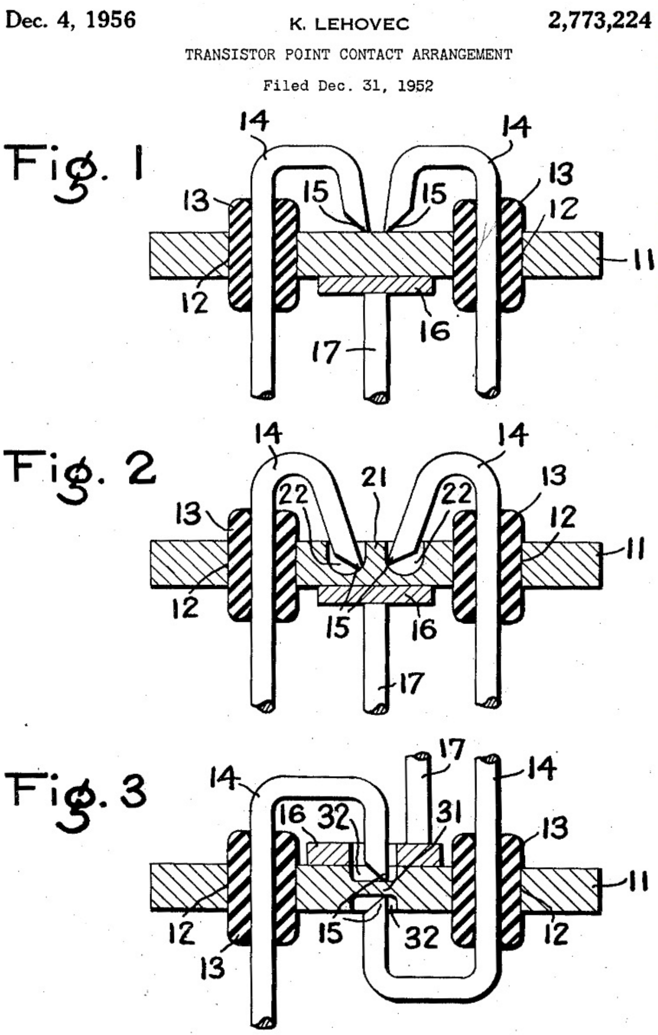
Helmar Frank was a Czechoslovak physicist of German nationality. […] He created the first Czechoslovak semiconductor amplifying component---the point-contact germanium transistor---and developed, initiated and helped to introduce production of semiconductor materials and components in many Czechoslovak factories.

National Academy of Sciences. 2011. *Jan Tauc 1922-2010.*
http://nas.nasonline.org/site/DocServer/Tauc_Jan.pdf

Jan's first job after graduation was at a government-supported research institute with a mission to develop electronic technologies (such as television and microwaves), using equipment and documentation left behind by the German army and declassified information from the West that became available after the war. The institute was located first in Tanvald, a mountainous region of northern Bohemia, which was the location of the former German army center. There Jan became involved in microwave detectors that the Germans had developed for the 10 cm wavelength band, using germanium. When the news of the invention of the transistor reached Prague, he used the germanium of those detectors to build the first point-contact transistor in Czechoslovakia and decided to stay in that field.

Figure 6.95: Helmar Frank and Jan Tauc produced transistors at the former German electronics laboratory in Tannwald/Tanvald in Czechoslovakia in 1949, based at least in part (and perhaps entirely) on wartime German work there.

Transistors (12)



Charles University, Prague

Bernhard Gudden (1892–1945)

Kurt Lehovec (1918–2012)

NARA RG 40, Entry UD-75, Box 28, Folder Edwin Y. Webb, Jr. 1945 memo from Harry Dauber.

Interrogate Dpl. Phys. Kurt Frank and Dr. K. Raithel on heat image tube (both were assistants of Prof. Gudden). ?
Dr. Martin Tren, Nurnberg (Arminiusstrasse 5) knows their address (check on Tren in FIAT files, his present address should be available there.

Kurt Lehovec, formerly Prof. Gudden's assistant in charge of rectifier research, should be interrogated and requested to expand on the information provided in FIAT FINAL REPORT No. 706. Lehovae was last known to work at the Weissenberg Laboratory of the SAF near Nuernberg. Documents pertaining to his work are at FIAT.

Figure 6.96: During the war, Bernhard Gudden and Kurt Lehovec ran a very secretive and well-funded group that was developing advanced semiconductor devices at Charles University in Prague. After the war, Gudden died in a Czech prison and Lehovec moved to the United States, where he filed patent applications on transistor designs, possibly based on the wartime work.

Transistors (12)
Bernhard Gudden and Kurt Lehovec

United States Patent Office

2,773,224
Patented Dec. 4, 1956

1

2,773,224

TRANSISTOR POINT CONTACT ARRANGEMENT

Kurt Lehovec, Williamstown, Mass., assignor to Sprague Electric Company, North Adams, Mass., a corporation of Massachusetts

Application December 31, 1952, Serial No. 328,948

6 Claims. (Cl. 317—235)

The present invention relates to new and improved point contact constructions for transistors.

The field of transistors is now so well known that it is not deemed necessary to devote any of the present specification to purely descriptive matter relating to this subject. In this connection, reference is made to the text "Holes and electrons in semiconductors" by Schockley, the entire November 1952 issue of the Proceedings of the Institute of Radio Engineers, as well as other publications.

One type of transistor which presently shows a great deal of promise requires the use of two point contacts termed the emitter and the collector bearing against a single crystal of a metal such as germanium, silicon, or other related semiconducting materials. A third low resistance electrical connection is made to such a crystal. In order to obtain satisfactory operating characteristics with this type of construction the two point contacts must be positioned relatively close, and must remain in a comparatively fixed position.

It is now a common procedure to hold these point contacts or probes in place by the use of a small amount of tension and a stiff gel-like filler material. Other means for accomplishing the same result have been suggested. These include the use of stiff fabric-like inserts through which the probes are inserted; the use of an adjacent wall upon which the point contacts are mounted; and other means. The number of suggestions made on the subject of positioning wire probes in itself indicates the ineffectiveness of the presently used procedures.

An object of the present invention is to improve upon the aforegoing and related methods for positioning wire point contacts against a body of a semiconducting material used in a transistor. A further object is to produce new and improved transistor constructions. These and other aims of the invention, as well as the advantages of it will be apparent from the following description and claims, as well as the accompanying drawings in which:

Figure 1 diagrammatically illustrates a transistor formed in accordance with this disclosure; and

Figure 2 is a diagrammatic view of a modified construction of the invention; and

Figure 3 is a diagrammatic view of a still further modified construction. In all figures like numerals designate like parts.

In Figure 1 of the drawings a simple transistor construction is shown in which a small semiconducting wafer **11** such as, for example, a germanium crystal about 30 x 50 x 150 mils in size is provided with two apertures **12** through which wire probes **14** project. Each of these probes **14** is insulated from the wafer **11** by an insulating sleeve **13** of polyethylene or the like, and is bent so that the point contacts **15** touch the same face of the crystal quite close to one another. Preferably a space of from 1 to 5 mils separates them. A low resistance contact **16** of known type is made to the wafer **11** through the wire **17**.

The modification shown in Figure 2 of the drawing

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differs from the construction of Figure 1 solely in that the adjacent point contacts **15** are positioned upon opposite sides of a wall **21** in small cavities **22** formed within the wafer **11**. Preferably, this wall **21** should be from about 1 to about 5 mils thick. The construction shown in this figure has the advantage that with it the point contacts are not apt to be dislodged due to handling, as when encasing the entire unit in a protective insulating resin.

The same advantage is derived from the construction illustrated in Figure 3. Here the wire probes **14** are inserted through the holes **12** in the wafer **11** from opposite directions so that the point contacts **15** project towards one another within the cavities **32**, but are separated by the wall **31** which is preferably of the thickness previously indicated.

The various apertures and holes or cavities herein indicated can be found in a variety of methods known to the art, such as, for example, by the use of dental abrasive equipment.

The herein described invention has a number of advantages. Perhaps one of the most important of these is comparative ease with which it adapts itself to large scale production techniques. By one procedure a comparatively large flat body of a semiconductor can be provided with the apertures, holes, and/or cavities for a large number of transistors at the same time, the appropriate connections and probes indicated can be placed in position, and then the individual transistors actually formed by cutting the larger body. If desired, the initial block can be scored or perforated so as to assist in separating the individual units. Various known steps, not specifically indicated herein, such as, for example, etching can be carried out at any convenient stage in forming the units of the invention. Also, a construction similar to that shown in Figure 1 can be formed utilizing a very thin wafer with the point contacts positioned upon opposite sides of it in the broad manner indicated.

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 transistor comprising a body of a semiconducting material, means defining at least two closely-spaced apertures through said body, wire probe means passing through said apertures, insulating means separating said wire means from said body in said apertures, point contact means formed on the tips of said probe means, said point contact means forming rectifying contacts with parts of said body about 1 to 5 mils apart.

2. A transistor as defined in claim 1 wherein said contacts are both on the same face of said body.

3. A transistor comprising a body of a semiconducting material, means defining at least two closely-spaced apertures in said body, wire probe means passing through said apertures, insulating means separating said wire means from said body in said apertures, point contact means formed on the tips of said probe means and positioned within cavities upon the same face of said body, said point contact means forming rectifying contacts with adjacent parts of said body.

4. A transistor comprising a body of a semiconducting material, means defining at least two closely-spaced apertures in said body, wire probe means passing through said apertures, insulating means separating said wire means from said body in said apertures, point contact means formed on the tips of said probe means positioned upon opposed sides of said body, said point contact means forming rectifying contacts with adjacent parts of said body.

Figure 6.97: During the war, Bernhard Gudden and Kurt Lehovec ran a very secretive and well-funded group that was developing advanced semiconductor devices at Charles University in Prague. After the war, Gudden died in a Czech prison and Lehovec moved to the United States, where he filed patent applications on transistor designs, possibly based on the wartime work.

6.5.4 Postwar Transfer of Microelectronics Technologies

Appendix B presents evidence that 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 (for examples, see pp. 1087–1088 and Section B.5).

- 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 by one source (p. 3027), "the semiconductor group at Bell Laboratories began its work with a survey of wartime developments in the field of semiconductors" [Eckert and Schubert 1990, p. 159].

- 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.).

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.

Figures 6.100–6.101 show examples of how detailed technical information on the German semiconductor and microelectronics technologies was transferred to Allied countries after World War II. For instance, BIOS Final Report 725, *German Research on Rectifiers and Semi-Conductors*, 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 [BIOS 725]:

> 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...

After the war, 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. 1162–1163, 2772, and 3025. Many other German-speaking scientists were hired by other U.S. laboratories or companies.

6.5.5 Capacitors

In addition to diodes and transistors, creators from the German-speaking world invented and perfected capacitors (sometimes called condensers), which temporarily store electric charge.

Ewald Georg von Kleist (German states, 1700–1748) invented and demonstrated the first capacitors in 1745; see Fig. 6.102. Pieter van Musschenbroek (Dutch, 1692–1761) conducted further experiments with capacitors, and they became known as "Leiden jars." Daniel Gralath (Danzig, 1708–1767) realized that multiple Leiden jars could be connected together to store more electric charge.

As shown in Fig. 6.103, Karol (Charles) Pollak (Polish, educated in Germany, worked in Germany and Austria, 1859–1928) invented the electrolytic capacitor in 1896. He also developed improved batteries and a variety of other electrical innovations.

Julius Edgar Lilienfeld invented and patented an improved design for electrolytic capacitors in 1931 (p. 1093).

In the 1930s, Eberhard Traub (German, 1906–20??) invented metallized paper capacitors, which worked well and could be manufactured very inexpensively. See Fig. 6.105.

The United States acquired Traub's metallized paper capacitor technology in 1945, as illustrated in Figs. 6.106–6.107. Traub's approach soon spread worldwide.

Examples of AT&T/Bell Labs/Western Electric active employees or longtime former employees involved in postwar technology transfer from Germany and Austria

CONFIDENTIAL

NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda

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.

DECLASSIFIED
Authority NND968018

Edwin Y. Webb Jr.	**AT&T 1928–1944. Chief for transferring electronics/communications technologies**
George Richert.	**Bell Telephone 1927–1942. Assistant Chief for transferring electronics/communications tech.**
Todos M. Odarenko	**Bell Telephone 1928–1943. Senior scientist for transferring electronics/communications tech.**
Julian Blanchard	**AT&T/Bell/Western Electric**
F. A. Cowan	**AT&T**
Lloyd Espenschied	**Bell Labs**
George W. Gilman	**Bell Labs**
Frederick Henderson	**Western Electric**
W. H. Martin	**Bell Labs**
Roland H. McCarthy	**Western Electric**
Pierre Mertz	**Bell Labs**
John A. Parrott	**AT&T**
R. E. Poole	**Bell Labs**
Victor Ronci	**Bell Labs**
R. E. Russell	**AT&T**
John N. Shive	**Bell Labs**
John R. Townsend	**Bell Labs**
John Bardeen*	**Bell Labs**
William Shockley*	**Bell Labs**

***See for example:**

Michael Eckert and Helmut Schubert. 1990. *Crystals, Electrons, Transistors.* pp. 158–163, 166.

Jon Gertner. 2012. *The Idea Factory: Bell Labs and the Great Age of American Innovation.* pp. 90–92.

Lillian Hoddeson and Vicki Daitch. 2002. *True Genius: The Life and Science on John Bardeen.* pp. 128–131.

Figure 6.98: Examples of AT&T/Bell Labs/Western Electric active employees or longtime former employees involved in postwar technology transfer from Germany and Austria [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda].

Examples of technology transfer to AT&T Bell Laboratories

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

DECLASSIFIED
Authority NND 968018

RB:EJ

"~~Institute~~ of the Bevallmaechtigter Fuer Hochfrequenz – Forschung"

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

DECLASSIFIED
Authority NND 968048

NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards

BELL TELEPHONE LABORATORIES
INCORPORATED
463 West Street
New York

O. E. Buckley
President

February 28, 1947

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 proceeding 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

DECLASSIFIED
Authority NND 968018

NARA RG 40, Entry UD-75, Box 24, Folder Bell System

Figure 6.99: Examples of technology transfer to AT&T Bell Laboratories [NARA RG 40, Entry UD-75, Boxes 24 and 58].

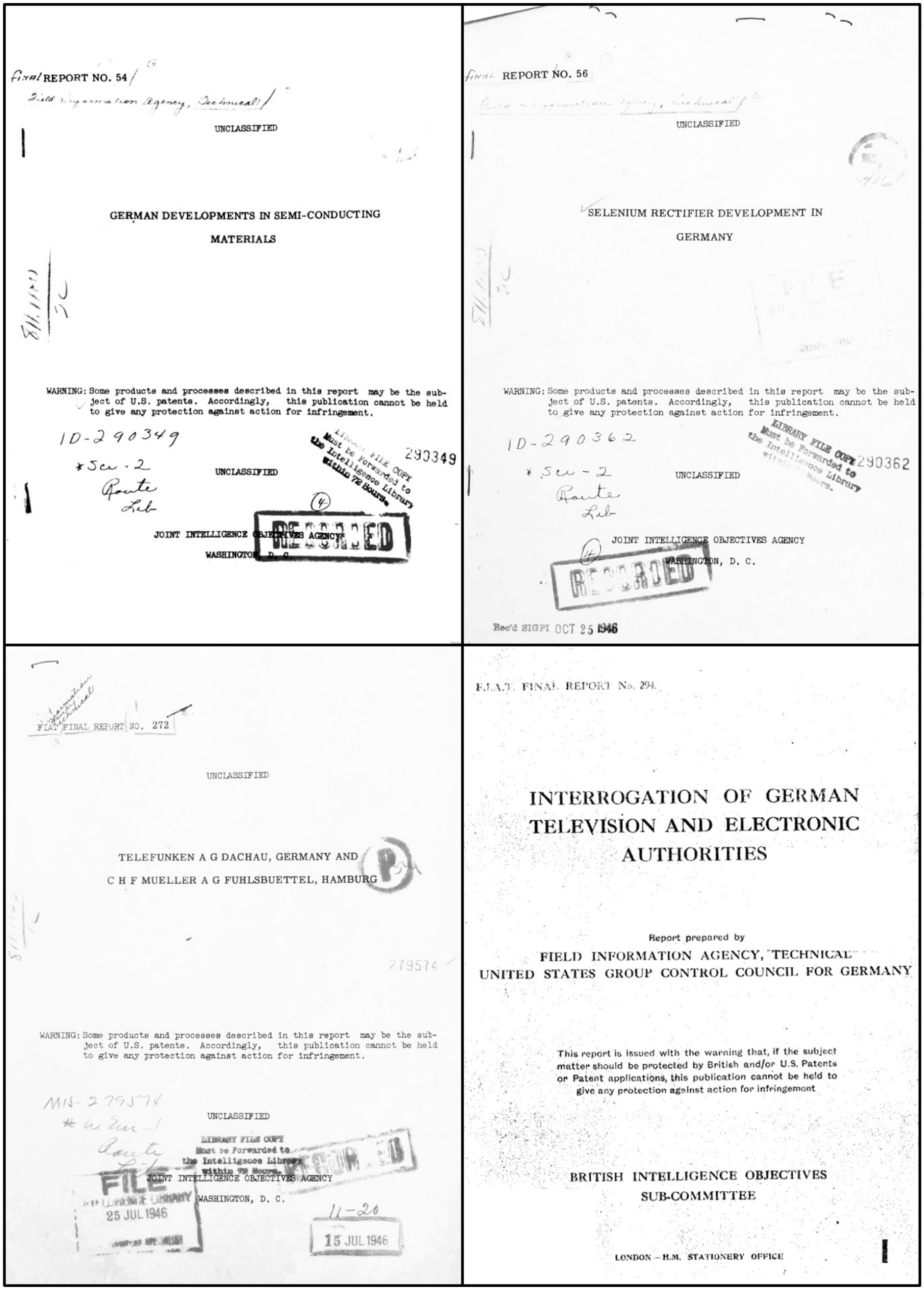
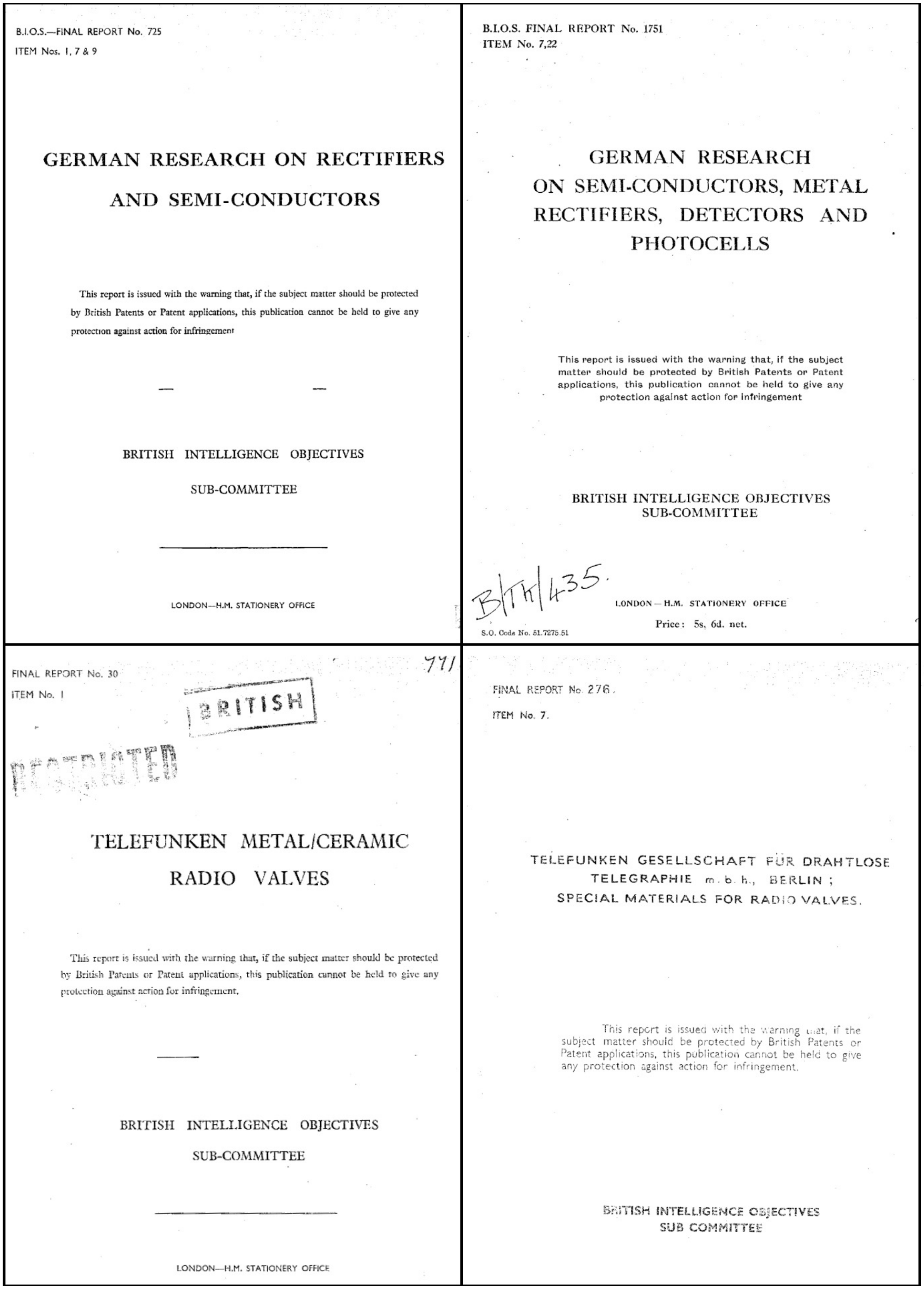


Figure 6.100: U.K. and U.S. officials investigated German microelectronics programs in detail in 1945 and wrote many reports about some of what they learned.



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

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

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

B/TK/435.

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Price: 5s. 6d. net.

S.O. Code No. 51.7275.51

FINAL REPORT No. 30
ITEM No. 1

771

BRITISH

TELEFUNKEN METAL/CERAMIC RADIO VALVES

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

FINAL REPORT No. 276.
ITEM No. 7.

TELEFUNKEN GESELLSCHAFT FÜR DRAHTLOSE TELEGRAPHIE m. b. h., BERLIN ;
SPECIAL MATERIALS FOR RADIO VALVES.

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

Figure 6.101: U.K. and U.S. officials investigated German microelectronics programs in detail in 1945 and wrote many reports about some of what they learned.

Ewald Georg von Kleist (1700–1748)	Pieter van Musschenbroek (1692–1761)	Daniel Gralath (1708–1767)


Capacitor, or Leiden jar (1745)

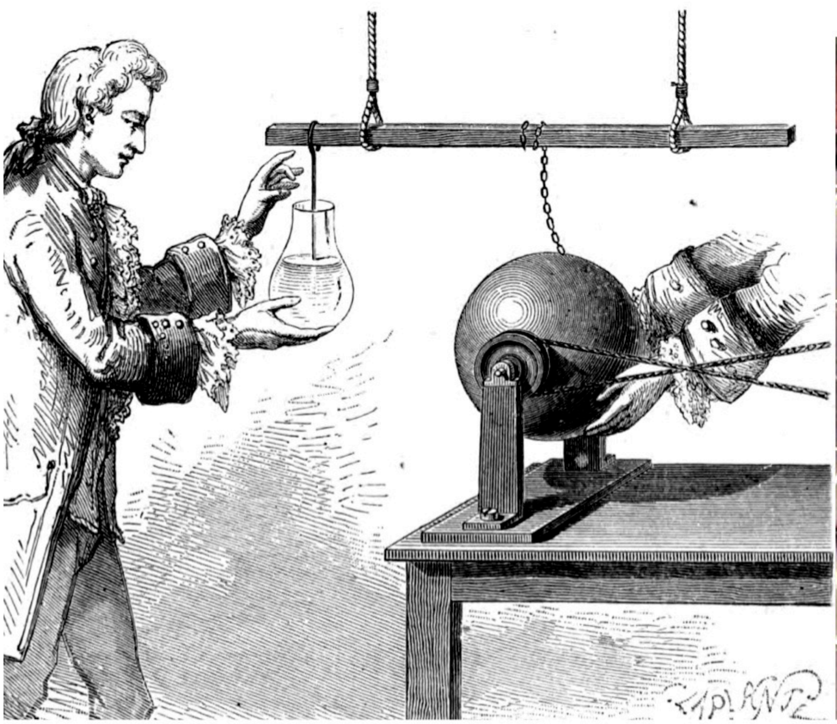
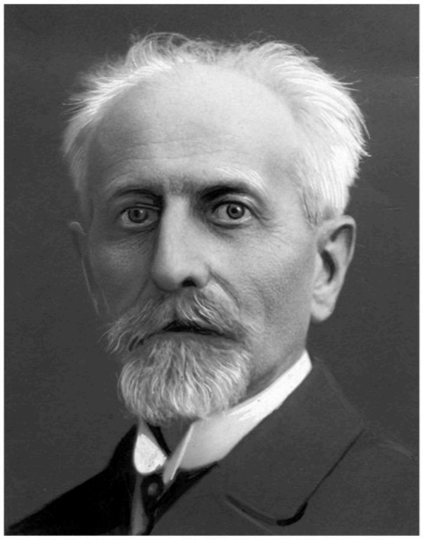



Figure 6.102: In 1745, Ewald Georg von Kleist invented the capacitor, which temporarily stores electric charge. Pieter van Musschenbroek conducted further experiments with capacitors, and they became known as "Leiden jars." Daniel Gralath realized that multiple Leiden jars could be connected together to store more electric charge.

Karol (Charles) Pollak (1859–1928) invented the electrolytic capacitor (1896) and improved batteries



SCHWEIZERISCHE EIDGENOSSENSCHAFT

EIDGEN. AMT FÜR GEISTIGES EIGENTUM

PATENTSCHRIFT

Patent Nr. 12503 10. Juni 1896, 7¾ Uhr, p. **Klasse 97**

Charles POLLAK, in FRANKFURT a/M. (Deutschland).

Akkumulatorplatte.

Der Gegenstand der Erfindung ist eine Akkumulatorplatte von großer Festigkeit und Dauerhaftigkeit, bei welcher sich der stromleitende Kern mit der porösen Oberfläche in innigster metallischer Verbindung befindet, wobei die poröse Schicht aus einer Fortsetzung und Verzweigung des Kernes selbst besteht.

Die Gestalt des massiven Kernes ist eine beliebige, die Beschaffenheit des porösen Teiles eine feinkörnige, um eine möglichst große, wirksame Oberfläche der Platte zu erhalten.

In Fig. 1 ist der Querschnitt einer solchen porösen Kernplatte in stark vergrößertem Maßstabe dargestellt. *a* bezeichnet den massiven Kern, *b* den porösen Teil der Platte. Der Kern *a* geht ohne jede Unterbrechung in die Verzweigungen *d* über, zwischen denen sich Öffnungen und Kanäle *c* befinden, welche dem Elektrolyt freien Zutritt gewähren.

Die Fig. 2, 3, 4 und 5 zeigen einige wichtigere Ausführungsformen des Kernes; bei diesen Darstellungen wurden der größeren Deutlichkeit wegen die Grenzen zwischen dem Kerne und dem porösen Teil durch punktierte Linien angedeutet, obwohl in der Wirklichkeit der Übergang des massiven Teiles in den porösen ein ganz allmählicher ist.

In Fig. 2 besteht der Kern *a* aus einer metallischen Schicht gleicher Stärke, welche sich nach und nach in den porösen Teil *b* verzweigt. In Fig. 3 hat der Kern die Gestalt eines Gitters; in Fig. 4 besteht derselbe aus einer mit Rippen *e* und zahlreichen Zacken *f* versehenen Platte *a*.

In Fig. 5 ist der poröse Teil *b* nur mit einem massiven Rahmen *a* umgeben, welcher, wie bei allen anderen Formen dieser Platten, ebenfalls mit dem porösen Teile ein einziges homogenes metallisches Stück bildet.

Platten für Akkumulatoren von solcher Beschaffenheit, daß zwischen Kern und porösem Teil keine Trennung besteht, weil beide Teile aus einer metallischen Masse bestehen, bieten den bisher bekannten gegenüber wesentliche Vorteile. Die Bildung des Superoxydes erfolgt in einer durchaus gleichmäßigen Weise nach und nach auf der äußeren Oberfläche aller Zwischenräume der porösen Schicht, ohne jedoch die wichtigen Verbindungsstellen (*d* in Fig. 1) zwischen Kern und porösem Teil angreifen und zerstören zu können, weil eben zwischen diesen Bestandteilen der Platte keine Trennung und keine Spalten vorhanden sind.

Die Stromzuführung kann vollständig gleichmäßig auf der ganzen Oberfläche des Kernes und des porösen Teiles erfolgen, wo-

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 19. MAI 189

PATENTSCHRIFT

— № 92564 —

KLASSE 21: ELEKTRISCHE APPARATE.

CHARLES POLLAK IN FRANKFURT A. M.

Elektrischer Flüssigkeitskondensator mit Aluminiumelektroden.

Patentirt im Deutschen Reiche vom 14. Januar 1896 ab.

Der Gegenstand der vorliegenden Erfindung ist eine Verbesserung der als elektrostatische Kondensatoren verwendeten Zersetzungszellen, welche bezweckt, die Leistungsfähigkeit und Dauerhaftigkeit dieser Kondensatoren zu erhöhen und dieselben dadurch technisch brauchbar zu machen.

Die Möglichkeit der Verwendung elektrolytischer Zellen als Kondensatoren von grofser Capacität wurde bereits mehrmals hervorgehoben und bei wissenschaftlichen Experimenten in kleinem Mafsstabe auch durchgeführt, wobei pro Zelle bezw. Elektrodenpaar Spannungsunterschiede bis zu 5,5 Volt beobachtet wurden. (Wiedemann, Lehre von der Elektricität, 2. Auflage, Band 2, S. 757.)

Bei der technischen Anwendung solcher Zellen stiefs man jedoch auf eine Reihe bedeutender Schwierigkeiten, namentlich auf die geringe zulässige Spannung an den Elektroden, grofse Stromverluste wegen unvollkommener Isolation und geringe Ausdauer der Zellen.

In den englischen Patentschriften Nr. 7509 und 14189 vom Jahre 1892 sind Vorschläge zur gewerblichen Verwerthung derartiger Kondensatoren enthalten, jedoch ohne Angabe der Mittel und Zusammenstellungen, welche dies ermöglichen sollen.

Den Ausgangspunkt zu der vorliegenden Erfindung bildet die im Jahre 1875 von Ducretet beschriebene Entdeckung, dafs das Aluminium als positive Elektrode einer Zelle mit angesäuertem Wasser als Elektrolyt sich mit einer isolirenden Schicht umgiebt und dem Durchgange des Stromes in dieser Richtung einen grofsen Widerstand entgegensetzt. Er beabsichtigte, diese Eigenschaft des Aluminiums zur Construction flüssiger Stromunterbrecher zu benutzen.

Wie die Erfahrung gezeigt hatte, war auch diese Ausführungsform noch nicht technisch verwerthbar, da die sich auf dem Aluminium in saurer Lösung bildende Schicht zu unbeständig ist und nach einiger Zeit von der Platte abblättert. Auch ist die bei einem Kondensator unbedingt erforderliche gute Isolation der Platte von der Flüssigkeit auf diesem Wege nicht zu erreichen. Der Erfinder hat die Beobachtung gemacht, dafs bei der von Ducretet angegebenen Zusammenstellung selbst mäfsige Spannungen von etwa 20 Volt nicht genügend gut durch die Isolir- bezw. Polarisationsschicht aufgehalten werden können. Die Technik braucht aber meistens nur Kondensatoren, die bei mindestens 65 oder 110 Volt arbeiten können.

Die gegenwärtige Erfindung ermöglicht nun die Herstellung einer vollkommen isolirenden Polarisationsschicht auf Aluminiumplatten durch entsprechende Wahl des Elektrolyten und Vorbereitung der Platten.

Die sich dabei auf dem Metalle bildende Schicht kann als Dielektricum eines Kondensators verwendet werden. Statt der sauren Lösung, wie bei Ducretet, nimmt man hierzu alkalische oder neutrale Lösungen, wie z. B. die neutralen Salze des Aluminiums, des Eisens, des Chroms u. s. w. Eine Ausführung der Erfindung wird an nachfolgendem Beispiel erläutert.

Eine Zelle mit alkalischer Lösung als Elektrolyt und zwei Aluminiumplatten als Elektroden

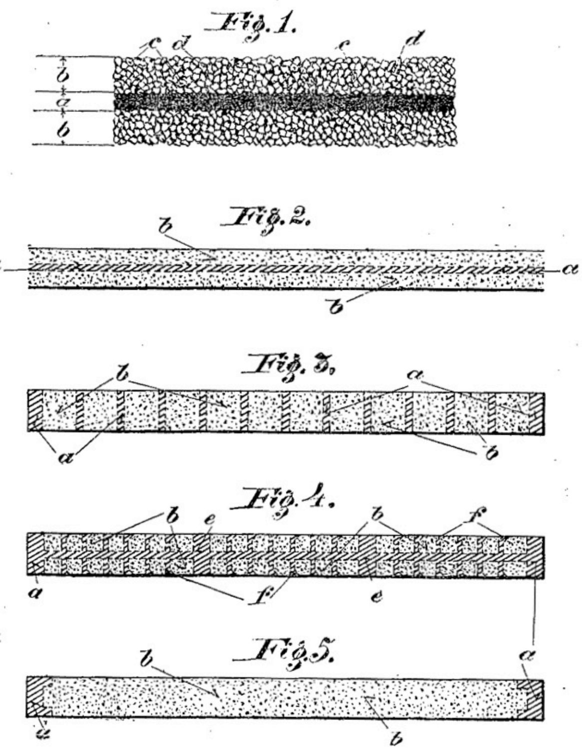
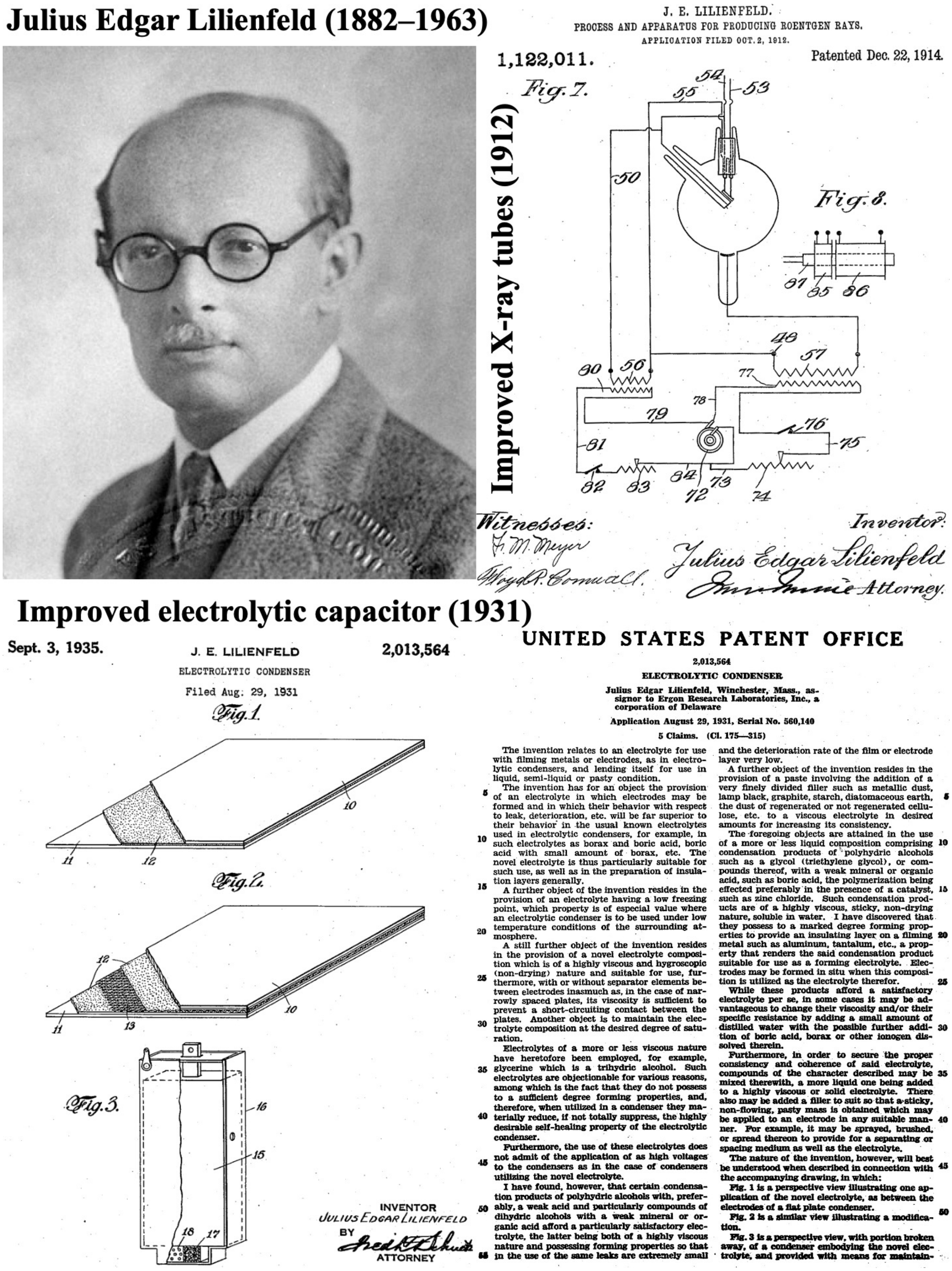


Figure 6.103: Karol (Charles) Pollak invented the electrolytic capacitor in 1896 and also developed improved batteries.



UNITED STATES PATENT OFFICE

2,013,564

ELECTROLYTIC CONDENSER

Julius Edgar Lilienfeld, Winchester, Mass., assignor to Ergon Research Laboratories, Inc., a corporation of Delaware

Application August 29, 1931, Serial No. 560,140

5 Claims. (Cl. 175—315)

The invention relates to an electrolyte for use with filming metals or electrodes, as in electrolytic condensers, and lending itself for use in liquid, semi-liquid or pasty condition.

The invention has for an object the provision of an electrolyte in which electrodes may be formed and in which their behavior with respect to leak, deterioration, etc. will be far superior to their behavior in the usual known electrolytes used in electrolytic condensers, for example, in such electrolytes as borax and boric acid, boric acid with small amount of borax, etc. The novel electrolyte is thus particularly suitable for such use, as well as in the preparation of insulation layers generally.

A further object of the invention resides in the provision of an electrolyte having a low freezing point, which property is of especial value where an electrolytic condenser is to be used under low temperature conditions of the surrounding atmosphere.

A still further object of the invention resides in the provision of a novel electrolyte composition which is of a highly viscous and hygroscopic (non-drying) nature and suitable for use, furthermore, with or without separator elements between electrodes inasmuch as, in the case of narrowly spaced plates, its viscosity is sufficient to prevent a short-circuiting contact between the plates. Another object is to maintain the electrolyte composition at the desired degree of saturation.

Electrolytes of a more or less viscous nature have heretofore been employed, for example, glycerine which is a trihydric alcohol. Such electrolytes are objectionable for various reasons, among which is the fact that they do not possess to a sufficient degree forming properties, and, therefore, when utilized in a condenser they materially reduce, if not totally suppress, the highly desirable self-healing property of the electrolytic condenser.

Furthermore, the use of these electrolytes does not admit of the application of as high voltages to the condensers as in the case of condensers utilizing the novel electrolyte.

I have found, however, that certain condensation products of polyhydric alcohols with, preferably, a weak acid and particularly compounds of dihydric alcohols with a weak mineral or organic acid afford a particularly satisfactory electrolyte, the latter being both of a highly viscous nature and possessing forming properties so that in the use of the same leaks are extremely small and the deterioration rate of the film or electrode layer very low.

A further object of the invention resides in the provision of a paste involving the addition of a very finely divided filler such as metallic dust, lamp black, graphite, starch, diatomaceous earth, the dust of regenerated or not regenerated cellulose, etc. to a viscous electrolyte in desired amounts for increasing its consistency.

The foregoing objects are attained in the use of a more or less liquid composition comprising condensation products of polyhydric alcohols such as a glycol (triethylene glycol), or compounds thereof, with a weak mineral or organic acid, such as boric acid, the polymerization being effected preferably in the presence of a catalyst, such as zinc chloride. Such condensation products are of a highly viscous, sticky, non-drying nature, soluble in water. I have discovered that they possess to a marked degree forming properties to provide an insulating layer on a filming metal such as aluminum, tantalum, etc., a property that renders the said condensation product suitable for use as a forming electrolyte. Electrodes may be formed in situ when this composition is utilized as the electrolyte therefor.

While these products afford a satisfactory electrolyte per se, in some cases it may be advantageous to change their viscosity and/or their specific resistance by adding a small amount of distilled water with the possible further addition of boric acid, borax or other ionogen dissolved therein.

Furthermore, in order to secure the proper consistency and coherence of said electrolyte, compounds of the character described may be mixed therewith, a more liquid one being added to a highly viscous or solid electrolyte. There also may be added a filler to suit so that a sticky, non-flowing, pasty mass is obtained which may be applied to an electrode in any suitable manner. For example, it may be sprayed, brushed, or spread thereon to provide for a separating or spacing medium as well as the electrolyte.

The nature of the invention, however, will best be understood when described in connection with the accompanying drawing, in which:

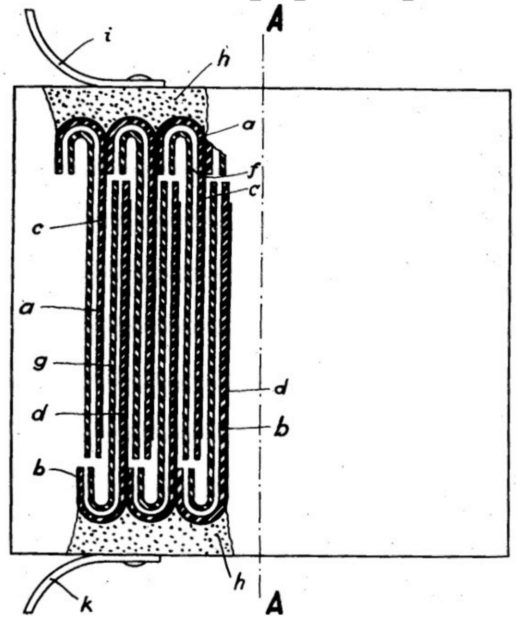
Fig. 1 is a perspective view illustrating one application of the novel electrolyte, as between the electrodes of a flat plate condenser.

Fig. 2 is a similar view illustrating a modification.

Fig. 3 is a perspective view, with portion broken away, of a condenser embodying the novel electrolyte, and provided with means for maintain-

Figure 6.104: Julius Edgar Lilienfeld invented an improved X-ray tube in 1912, the field effect transistor in 1925, and an improved electrolytic capacitor in 1931.

Eberhard Traub (1906–20??) invented metalized paper capacitors



Patented June 3, 1941 2,244,090

UNITED STATES PATENT OFFICE

2,244,090

CONDENSER WITH METALIZED DIELECTRIC

Eberhard Traub, Stuttgart, Germany, assignor to Robert Bosch Gesellschaft mit beschränkter Haftung, Stuttgart, Germany

Application July 6, 1937, Serial No. 152,157
In Germany August 4, 1936

14 Claims. (Cl. 175—41)

This invention relates to condensers with metalized dielectric in which therefore no independent metal foil is used but for the making of which a dielectric serves upon which the condenser covering is produced by spraying, rolling, in particular, however, by atomization (cathode atomization) or by the vaporization of metal or is otherwise directly produced. In such condensers contact difficulties easily result at the current connections, in particular when the condenser covering is very thin, for example if it is less than 0.002 mm. or 0.001 mm.

In such condensers in order to secure a lasting current connection it has been proposed according to application Serial No. 22,072 that an edge of the dielectric provided with the metallic covering is turned down 180° so that the metal covering will come on the outside. The contact for the current is attached to the turned down edges left free after the assembling. If such a condenser is constructed only of metalized dielectric then we shall have on the turned down edges a direct contact with the metalized surface of the adjacent layers of the same potential. However if we use besides the metalized also intermediate layers of non-metalized dielectric then measures must be taken if we wish to obtain a mutual contact of the adjacent layers of the same potential.

We may obtain a simple condenser structure according to the invention if we turn down not only the edge of the metalized dielectric layers but also the edge of the non-metalized dielectric layers, and that in such manner that the folded edges of the non-metalized dielectric layers will come within the turned down fold of the metalized dielectric.

In the drawing is shown an embodiment of the invention and in particular the drawing shows a coiled condenser in general view and partial section, in which the section shows the individual dielectric layers in considerably increased thickness. A—A indicates in the drawing the center line of the condenser. For the construction of the coil, in the embodiment shown, metalized paper is employed, especially paper which has received vaporized metal (zinc or cadmium for example) or has been metalized by cathode atomization. By *a* is designated the one and by *b* the other metalized paper strip. *c* is the metal coating upon the strip *a* and *d* the metal coating upon the strip *b*. The metal coatings or coverings have a thickness of about 0.0001 mm. *f* and *g* are two non-metalized paper strips. The non-metalized paper strips are, just like the metalized paper strips, turned down at one edge of the condenser by 180° and that in such a way that the turned down edges of the strips *f* and *g* will lie within the turned down folds of the strips *a* and *b*.

On the front sides of the condenser on the turned down edges of the metal coverings *c* and *d* lying exposed to the outside is attached the connection for the current. It consists of a metal coating *h* which is specially produced by spraying thereupon. The metal covering *h* should not be too thick as otherwise it will be too brittle. It must be merely so thick (say 0.3 to 0.5 mm.) that a terminal wire can be soldered thereon. In the drawing *i* and *k* indicate the two connecting wires.

The individual coatings do not have in a radial direction, as is shown in the drawing for sake of clearness, an interval between one another but are rolled directly on one another.

In the example of the invention between the two metalized paper strips *a* and *b* only one non-metalized paper strip *f* and *g* is used respectively. If we use between the metalized dielectric coatings a plurality of non-metalized dielectric coatings then we turn down the edges of all non-metalized coatings and that in such fashion that the folded edges of the metalized coatings will overlap them.

What is claimed is:

1. A condenser comprising successive layers of metalized and non-metalized insulating material arranged so that the metalized and non-metalized layers alternate with each other, alternate metalized layers being brought into contact with each other at one edge by folding over one edge of said alternate metalized layers and the cooperating non-metalized layers so that the folded edge of a non-metalized layer lies within the fold and the metal coating of the metalized layer faces the outside of the fold.

2. A condenser comprising successive layers of metalized material separated by layers of non-metalized material, one edge of a metalized layer and the adjacent edge of a non-metalized layer being folded upon themselves and the opposite edge of the next metalized layer and the adjacent edge of a non-metalized layer being folded upon themselves so that each folded edge of the non-metalized layer lies within a fold and the metal coating of each metalized layer faces the outside of a fold, the metal coated corners of such folds providing metal coated edges lying exposed at the sides of said condenser, and a metal coating connecting said coated edges.

3. A condenser comprising strips of metalized and non-metalized insulating material wound up in the form of a roll to provide successive layers of metalized insulating material separated by layers of non-metalized insulating material, one edge of each metalized strip and the adjacent edge of each non-metalized strip being folded upon themselves so that the folded edge of each non-metalized strip lies within a fold and the metal coating of each metalized strip faces the outside of a fold and contacts the adjacent coating of the same polarity, the folded edges of one set of cooperating metalized and non-metalized strips lying adjacent to but spaced from the unfolded edges of the next set of cooperating metalized and non-metalized strips, the metal coated corners of such folds providing continuous metal-coated edges lying exposed at the sides of said condenser, and condenser terminals connected to said fold corners.

4. A condenser comprising at least two strips of insulating material wound up in the form of a roll, one side of one of said strips being provided with a coating of metal, an edge of a coated strip and an edge of an uncoated strip being folded upon themselves so that the folded edge of the uncoated strip lies within the fold and the metal coating of the coated strip faces the outside of the fold to thereby provide a continuous metal-coated edge exposed at the side of the condenser to form a surface for connection of a terminal of the condenser.

5. A condenser comprising two strips of metalized paper and at least two strips of non-metalized paper wound up in the form of a roll with the metalized strips alternating with the non-metalized strips, one edge of one metalized strip and the adjacent edge of a non-metalized strip being folded upon themselves and the opposed edges of the other metalized and non-metalized strips being folded upon themselves so that each folded edge of the non-metalized strip lies within a fold and the metal coating of each metalized strip faces the outside of a fold and contacts the adjacent coating of the same polarity, the metal coated corners of such folds providing continuous metal-coated edges lying exposed at the sides of said condenser, and condenser terminals connected to said fold corners.

6. A condenser as set out in claim 5, in which the thickness of the metalization is about 0.0001 mm.

7. A condenser comprising successive layers of metalized and non-metalized paper, one edge of adjoining metalized and non-metalized layers being folded upon themselves at an angle of 180° so that the metal coating of the metalized layer faces the outside of the fold with the folded edge of the non-metalized layer within the fold, the metal-coated corners of such folds lying exposed at the sides of the condenser, and a metal coating applied to and connecting said fold corners.

8. A condenser comprising a plurality of superposed layers of metalized dielectric and intermediate layers of non-metalized dielectric, alternate metalized layers of said metalized dielectric being brought into metallic contact with each other by folding over the edges of said layers and the cooperating non-metalized layers so that the metalization faces the outside of the folds and provides a plurality of metal-coated folded edges at opposite sides of the condenser, the folded edges of the non-metalized layers each lying within a fold.

9. A condenser as set out in claim 8, including a metal coating connecting said metal-coated folded edges and providing condenser terminals.

10. A condenser as set out in claim 8, in which the thickness of the metalization is less than 0.001 mm.

11. A condenser comprising two strips of metalized paper and at least two strips of non-metalized paper wound up in the form of a roll with the metalized strips alternating with the non-metalized strips, one edge of one metalized strip and the adjacent edge of a non-metalized strip and the opposed edges of the other metalized and non-metalized strips being folded longitudinally upon themselves at an angle of 180° so that each folded edge of the non-metalized strips lies within a fold of the metalized strips and the metal coating of each metalized strip faces the outside of a fold and is in metallic contact with the next succeeding coating of the same polarity, the metal-coated corners of said folds providing continuous metal-coated edges lying exposed at and forming the sides of said condenser, a terminal metal layer applied to each side of said condenser and electrically connecting said metal-coated corners, and a terminal conductor soldered to each terminal metal layer.

12. A condenser as set out in claim 11, in which the metalization has a thickness of about 0.0001 mm.

13. A condenser comprising two strips of metalized paper and at least two strips of non-metalized paper wound up in the form of a roll with the metalized strips alternating with the non-metalized strips, the metalization of each metalized strip extending to one edge thereof, a non-metalized margin remaining along the opposite edge of each strip, the metalized edge of one metalized strip and the adjacent edge of a non-metalized strip being folded upon themselves and the metalized edge of the other metalized strip and the adjacent edge of the other non-metalized strip being folded upon themselves so that each folded edge of the non-metalized strips lies within a fold and the metalization of each metalized strip faces the outside of a fold and contacts the adjacent metalization of the same polarity, the metal coated corners of such folds providing continuous metal coated edges lying exposed at and forming the sides of said condenser, and a metal coating applied to and connecting said fold corners at each side of said condenser.

14. A condenser comprising two strips of metalized paper and at least two strips of non-metalized paper wound up in the form of a roll with the metalized strips alternating with the non-metalized strips, the metalization of each metalized strip having a thickness of less than 0.001 mm. extending to one edge thereof, a non-metalized margin remaining along the opposite edge of each strip, the metalized edge of one metalized strip and the adjacent edge of a non-metalized strip being folded upon themselves and the metalized edge of the other metalized strip and the adjacent edge of the other non-metalized strip being folded upon themselves so that each folded edge of the non-metalized strips lies within a fold and the metalization of each metalized strip faces the outside of a fold and contacts the adjacent metalization of the same polarity, said strips being arranged with the metalized edge of one metalized strip and the non-metalized edge of the other metalized strip adjacent to but spaced from each other, the metal coated corners of the folded edges of said metalized strips being arranged alternately at opposite sides of the condenser to provide continuous metal coated edges lying exposed at and forming the sides of said condenser, and a metal coating applied to and connecting said exposed folded metal coated edges at each side of said condenser.

EBERHARD TRAUB.

Figure 6.105: Eberhard Traub invented metallized paper capacitors.

United States acquired Eberhard Traub's metalized paper capacitors

ITEM No. 1
FILE No. XXVII–44

MANUFACTURE OF METALIZED PAPER CAPACITOR UNITS ROBERT BOSCH, STUTTGART

COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

TARGET

Office of Robert Bosch Company
Stuttgart, Germany
Dispersal Plant
Tubingen, Germany

PHYSICAL CONDITION OF TARGET

The main plant at Stuttgart is proably 98% destroyed, however, they have about 60 Dispersal plants located within a 50 mile radius of Stuttgart.

PLANT PERSONNEL

The following personnel were interviewed:

Dr. Wild - Director of Research
Dr. Dipper - Assistant Director of Research
Dr. Dorn - Research Specialist on Fixed Paper Capacitors

RESUME OF INTELLIGENCE GAINED BY INVESTIGATION

. Several years ago The Robert Bosch Company undertook the development of fixed paper capacitors which had the metal foil used in the conventional fixed paper capacitor replaced by the application of a very thin metallic coating directly onto the paper dieelectric. This Company has produced many millions of these condensers for use in both alternating and direct current circuits with very satisfactory results. After a careful study of the manufacturin processes involved in the production of this type of conden and an evaluation of the advantages and economies which can be gained by the use of this type of condenser as compared with the conventional type the following recommendation is made. If a manufacturer of fixed paper condensers in the United States wished to go into the production of metalized paper condensers and was willing to spend about 25,000 dollars for the design and production of the two special machines, he would be in a position to produce fixed paper capacitors which are about 40% smaller than the paper and foil type and which could be produced at 20% reduction in cost. These advantages would very quickly pay for the investment in the special

- 3 -

July 23, 1945

TO: Major Gen. G. L. Van Deusen
Chief, Engineering & Technical Service
Office of the Chief Signal Officer
Pentagon Bldg., Room 3E-348
Washington 25, D. C.

SUBJECT: Shipment of German Capicator Machine to Ft. Monmouth

1. The writer has recommended to Col. Urhane and Major Neal Crane, Technical Liaison Division, O C Sig. O, Hq. Com. Z, APO 887, that the Signal Corps evacuate for shipment to Ft. Monmouth one machine and the control equipment for the manufacture of paper capacitors from the Bosch plant at Stuttgart, Germany.

2. The process is covered by U.S. Pat. 2,244,090 in the custody of the Alien Property Custodian, who has requested TIIC to secure additional information on the process, which has been done by investigator F. E. Henderson, loaned by the Western Electric Co. His report on the process should be available from TIIC, Washington, in about 30 days. Mr. Henderson may be reached for first-hand information, if and when desired, at the Point Breeze plant of Western Electric at Baltimore after 20 August.

3. Bosch states that they have furnished about 40 million capacitors of this type to the German military. The units are far more compact than anything we have produced and are familiar to all Signal Corps personnel who have examined captured German radio equipment. However, an important item that is probably not known is that they are self-healing on repeated breakdowns caused by over-voltage surges. The value of this feature, if true, is too evident to be dwelt on here.

4. This self-healing feature probably explains the Germans would risk using a single sheet of 0.4-mil Kraft paper as a suitable capacitor dielectric for a m imum working voltage of 250-dc.

5. The salient features of the construction are these: An extremely thin film of bakelite varnish is applied to one side of the paper, following which zinc vapor is applied in a vacuum. The thickness of the zi film on the paper is about 2 microns. Consequently, should a voltage break-down occur, due to a pin hole o weak spot in the dielectric, the extremely thin film o zinc acts as a fuse and the capacitor practically alway "burns open" instead of a short-circuiting, as is the c with the conventional rolled paper, metal foil, capacit

6. The remainder of the construction features ar adequately described in the patent. The machine for ac plishing the above operations is very ingeneously desig and for this reason it is considered desirable to have one available for examination in the event manufacture of these capacitors in the U.S. is decided upon.

7. It is recommended that SCGSA be requested to investigate the information referred to in Para. 2 as it becomes available and to furnish their comments and recommendations as to the practicability of initiating the manufacture of these capacitors in the U.S. either by means of a development contract, or other suitable means.

Dr. H. S. [illegible]
Consultant
O C Sig. O

U.S. Embassy, F.M.A.
APO 413, New York

Figure 6.106: The United States acquired Eberhard Traub's metallized paper capacitor technology in 1945.

DECLASSIFIED
Authority NND 968148

NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards

IV

BOSCH METALLIZED PAPER CONDENSER

Another of the many developments discovered in Germany which has aroused wide-spread interest among American manufacturers is an ingenious machine which applies a vaporized zinc coating to paper used in the manufacture of electrical condensers.

The patent for this process was on file in this country in the office of the Alien Property Custodian. An American condenser manufacturer who had contracts with the Army and Navy attempted to use this process because the condensers produced by its application were excellently suited for the equipment requirements under the contracts. However, the manufacturer was unsuccessful in his efforts to utilize the information thus available because of inability to comprehend certain details. The Alien Property Custodian requested that additional information be obtained for the benefit of this manufacturer and others, and American investigators undertook to obtain it.

The inventor of the process and the working machine were found at the Robert Bosch plant in Stuttgart where the development resulted from wartime research. The condenser has several important advantages over the conventional types manufactured in this country. A very thin metallic coating applied directly to the paper dielectric is used in place of the metal foil used in condensers produced domestically. This feature permits automatic healing after a breakdown occurs which is due to the fact that the very thin vaporized metallic film completely evaporates around the point of the breakdown so that an adequate insulation margin is again provided. Thus, numerous breakdowns may occur before the effective value of the condenser area is reduced beyond a workable limit. Because of this characteristic the condenser can be operated at 20 per cent to 50 per cent higher voltage than is possible with the conventional type. Also, the condensers are 40 per cent smaller and manufacturing costs can be approximately 20 per cent less than for those made by American firms.

The degree of interest that American industry has in this development is indicated by the fact that since the equipment has been evacuated to this country and condensers have been manufactured by the machinery which was set-up and put into operation in the Western Electric Company Hawthorne Plant in Chicago, the leading domestic manufacturers of condensers have become vitally interested in using the process.

Many millions of condensers are used in this country in the Electric and Electronics and Communications industries, and radio and radar could not have been perfected without them. This new process will revolutionize the manufacturing of these condensers, reducing their size and their cost and improving the reliability of the apparatus using them.

Information pertaining to this development is contained in Reports No. PB-39361 and PB-39361-S available through the Office of Technical Services of the Department of Commerce.

See attached letters.

Figure 6.107: The United States acquired Eberhard Traub's metalized paper capacitor technology in 1945 [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

6.5.6 Printed Circuits

While moving from large vacuum tubes to small transistors greatly helped to miniaturize and simplify electronics, the development of printed circuit boards was another major step in microelectronics. In printed circuits, electronic components are attached to an insulating board that is covered with etched metal lines for wires, avoiding the labor and bulkiness involved in connecting separate physical wires to each component. A closely related technological development was multipin connectors, which could be used without printed circuits but became even more advantageous when used together with printed circuits.

As shown on pp. 1099 and 2778–2789, Albert Hanson (German, 18??–19??) filed patent applications on printed circuits and multi-pin connectors in 1902 and 1903. From the available documentation, it is not clear how far he got in implementing his designs, although the highly detailed nature of the patents suggests that he may well have built and tested printed circuits and multi-pin connectors.

Mathias Nowottnick, an engineering professor at the University of Rostock, noted that printed circuit technology, apparently based on Hanson's patents, was being used by at least three German companies by 1927–1932 [Nowottnick 2014, p. 4]:

> 1927 Telefunken, Verdrahtung von Bauteilen mittels Messingstreifen.
>
> 1930 Hescho-Werke in Hermsdorf Aufdrucken von Leiterzügen auf Keramiksubstrat mittels Siebdrucktechnik (stellt heute noch die Grundlage für die Dickschichttechnik dar!)—“Gedruckte Schaltung”.
>
> 1932 erste Leiterplatte mit genieteten Metallstreifen, Sachsenwerk Licht und Kraft AG [Fig. 6.109]

> 1927 Telefunken, wiring of components using brass strips.
>
> 1930 Hescho Works in Hermsdorf Imprinting of conductors on ceramic substrate using screen printing technology (still the basis for thick-film technology today!)—“printed circuits.”
>
> 1932 first printed circuit board with riveted metal strips, Sachsenwerk Light and Power AG [Fig. 6.109]

Wolfgang Scheel, a longtime department head of the Fraunhofer Institute, named additional German companies that were among the first to use printed circuits [Manfred Frank 2003, p. 2]:

> Lassen Sie mich zunächst feststellen, dass die Leiterplatte in diesem Jahr [2003] ihren 100. Geburtstag feiert. Der Berliner Hanson hat dafür das Patent 1903 angemeldet. Ferner möchte ich anmerken, dass als Pionierfirmen auf dem Gebiet der Leiterplattenentwicklung in Deutschland die Sachsenwerk Licht und Kraft AG Niedersedlitz, die Ruwelwerke Geldern, die Lackwerke Peters in Kempen und die Isola AG in Düren zu nennen sind.

> Let me first note that the printed circuit board celebrates its 100th birthday this year [2003]. Hanson from Berlin filed the patent for it in 1903. I would also like to note that the pioneering companies in the field of printed circuit board development in Germany are Sachsenwerk Licht und Kraft AG Niedersedlitz, Ruwelwerke Geldern, Lackwerke Peters in Kempen and Isola AG in Düren.

Paul Eisler (Austrian, 1907–1992) studied engineering at the University of Vienna, graduated in 1930, and worked in electrical engineering, during which time he apparently became familiar with then-current German and Austrian printed circuit technologies that were based on Hanson's original patents. In 1936 Eisler fled to the United Kingdom, taking his knowledge of printed circuit technologies with him, and he immediately began building printed circuits upon his arrival there [Eisler 1989; Medawar and Pyke 2000]. He brought the technology to the attention of the British government during World War II and filed patent applications on it in 1944 (pp. 1101 and 2791–2807). Some U.S. officials discovered Eisler's work and incorporated simple printed circuits into proximity fuses for artillery shells that were used in late 1944 and 1945, but otherwise Allied countries do not seem to have harnessed the potential of printed circuits during the war.

In contrast, as shown on pp. 1102 and 2808–2811, printed circuits were in "wide use" in wartime Germany (presumably having grown far beyond just Telefunken, Hescho-Werke, and Sachsenwerk since ∼1930), and all of that printed circuit technology was transferred to the United States on a large scale after the war by people such as longtime Bell Telephone Laboratories engineer Todos Odarenko.

The final step in the development of printed circuits came when Rudolf Strauss (German, 1913–2001, Fig. 6.112) developed the wave soldering method for the fully automated manufacturing of printed circuits, or surface mount technology (SMT), from 1951 to 1955 [rondinax.wordpress.com/2014/01/31/rudolf-strauss-1913-2001-a-key-player-in-the-rondinax-and-rondix-story/]. See also pp. 2812–2818. (Was Strauss truly the original creator of wave soldering, or did he bring that method with him from the German-speaking world, just as Eisler apparently brought printed circuits?)

Historians of science Jean Medawar and David Pyke emphasized the importance of the development of printed circuits [Medawar and Pyke 2000, p. 93]:

> Rudolf Strauss [...] met and became friends with Paul Eisler, a refugee from Austria, who had invented the printed electrical circuit board, which revolutionized the electronics industry. Strauss invented a technique for soldering thousands of electric connections in one operation. His 'wave soldering' machine, built in 1958, is still being made in a sophisticated form all over the industrial world. [...]
>
> Recognition of Eisler's work took years. In late 1957 Lord Hailsham told the Royal Society that he rated the printed electric circuit as important an invention as penicillin or atomic fission.

Note that Medawar and Pyke described Eisler as the inventor of printed circuits, as have many other modern historians. While Eisler played a critical role in transferring printed circuit technology out of the German-speaking world and producing the first printed circuits in Allied countries, it seems clear from the historical record that Albert Hanson was the original inventor in 1902, and that multiple companies in the German-speaking world were building and selling printed circuits several years before Eisler ever built his first printed circuit board.

Boris Chertok, who led some of the Soviet missions removing German technologies after World War II, mentioned the widespread German use of sophisticated multi-pin connectors. Those likely went along with printed circuits, since printed circuits were in wide use and both multi-pin connectors and printed circuits traced back to Albert Hanson's inventions. Chertok also described the transfer of many other advanced electronics technologies to the Soviet Union (pp. 2819–2824).

Much more archival research is needed to reconstruct the detailed history and extent of research and development of printed circuits in the German-speaking world, as well as how that work was transferred to other countries during and after the Third Reich.

Albert Hanson (18??–19??) filed detailed patent applications on printed circuits and multi-pin connectors 1902–1903

Nº 15,077 A.D. 1903

Date claimed for Patent under Patents Act, 1901, being date of first Foreign Application (in United States), 7th July, 1902

Date of Application (in the United Kingdom), 7th July, 1903

Accepted, 7th Oct., 1904

COMPLETE SPECIFICATION.

Improvements in Automatic Switchboards for Telephone and like Exchanges.

I, Albert Parker Hanson, of 6 Lützow, Charlottenburg, in the Kingdom of Prussia, Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

My invention relates to the construction and disposition of apparatus in automatic exchanges, that is, centrals in which a number of selective switches, worked from a distance, are installed. Such plants are for example employed in so-called "automatic" telephone service. A single selective mechanism proper of such a plant with its box or frame will be called here the "switch", while the imaginably closed bounded field within which the lines leading to or past the switch are made accessible for purposes of making contact will be called a "contact field". A bank of contacts is a number of conducting bodies so arranged and held together as to present a contact field to the switch.

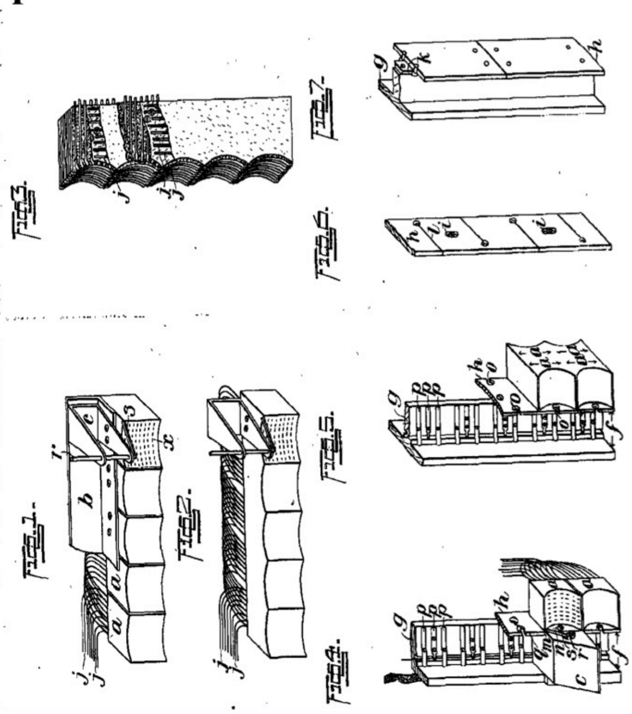
The purpose of my invention is to provide methods by which simplicity in manufacture, ease of transport and installation, accessibility in operation, facility in handling in service and economical use of space are insured.

These advantages I secure singly or in various combinations by incorporating numbers of contact banks into more or less rigid rows, independently of the switches to which they belong, and providing for their advantageous disposition at the central.

A very important feature of the invention is its allowing of many and varied forms each bringing with it a series of practical arrangements. Thus, in the forms hereinafter described in illustration of the invention, the advantages above enumerated are secured in an advancing degree even while the cost of manufacture per unit of apparatus is constantly decreasing.

Arrangements of wires or other conductors running parallel to each other, practically like zither-strings, and forming contact fields for switches arranged in a row parallel to them are already known—see British Patents, No. 8607/94 and 23239/'97, also U.S. Patent No. 626983, Decker Fig. 15.

My invention, however, is not affected by these and similar arrangements as heretofore applied. The contact banks employed by me are such as—in order



Nº 4681 A.D. 1903

Date of Application, 27th Feb., 1903

Complete Specification Left, 28th Dec., 1903—Accepted, 27th May, 1904

PROVISIONAL SPECIFICATION.

Improvements in or connected with Electric Cables and the Jointing of the same.

I, Albert Parker Hanson, of 43 Dorotheenstrasse, Berlin, in the Kingdom of Prussia, Engineer, do hereby declare the nature of this invention to be as follows:—

My invention relates to improvements in or connected with electric cables and the jointing of the same, by means of which certain advantages are obtained; and it is specially though not exclusively applicable for telephone exchange purposes where it is desirable to have a large number of conductors led to the switch boards or switching devices within very small compass and yet with each conductor or group of conductors readily accessible for jointing, replacing or other purposes.

A cable constructed under my invention may be broadly stated to be one in which a number of conductors are arranged between layers of paper or other suitable material the said material being when desired perforated or arranged so as to leave gaps or openings for jointing or other desired purposes.

In order that the nature of my invention may be more readily understood I shall proceed to briefly refer to certain contemplated forms thereof which will I anticipate give good results in practice. In all the forms hereinafter mentioned the conductors may be bare or insulated in any convenient manner and they may be arranged singly or in pairs for working on metallic circuit and they may be crossed at intervals for the purpose of avoiding induction sounds.

In one contemplated form, the conductors are spaced apart and glued or cemented to sheets of paper and these are built up so that the cable consists of alternate layers of separated wires and of paper paraffined or otherwise treated when desired. Instead of paper, fabric or tissue of any desired material may be employed.

In another contemplated form instead of separating the conductors by flat strips or sheets of paper or other material they may be separated by a single sheet or strip which is folded or corrugated longitudinally. The wires are then placed at the bottoms of the folds or corrugations and the upper parts of the said material are then bent over laterally so that each conductor lies in a kind of elongated pocket and is completely separated from its neighbours.

In a third form the conductors may simply rest between two layers of insulating material without being either cemented to or folded into the said material.

In a fourth contemplated form instead of separating the conductors by continuous lengths of paper or other material I use a number of short strips or layers of the latter spaced some distance apart so as to leave the conductors visible and accessible at intervals.

In a fifth contemplated form instead of using flat strips or layers, whether long or short, I employ corrugated strips or sheets, either long or short, and

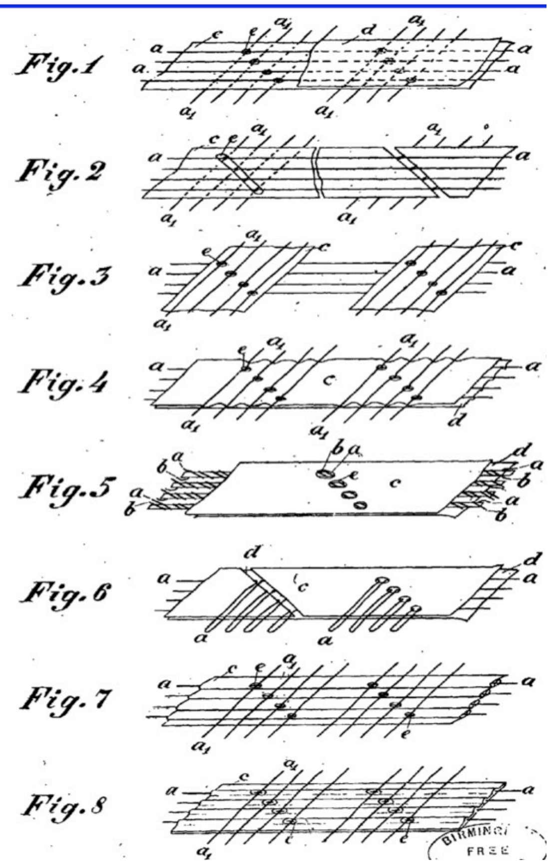


Figure 6.108: Albert Hanson filed detailed patent applications on printed circuits and multi-pin connectors in 1902 and 1903.

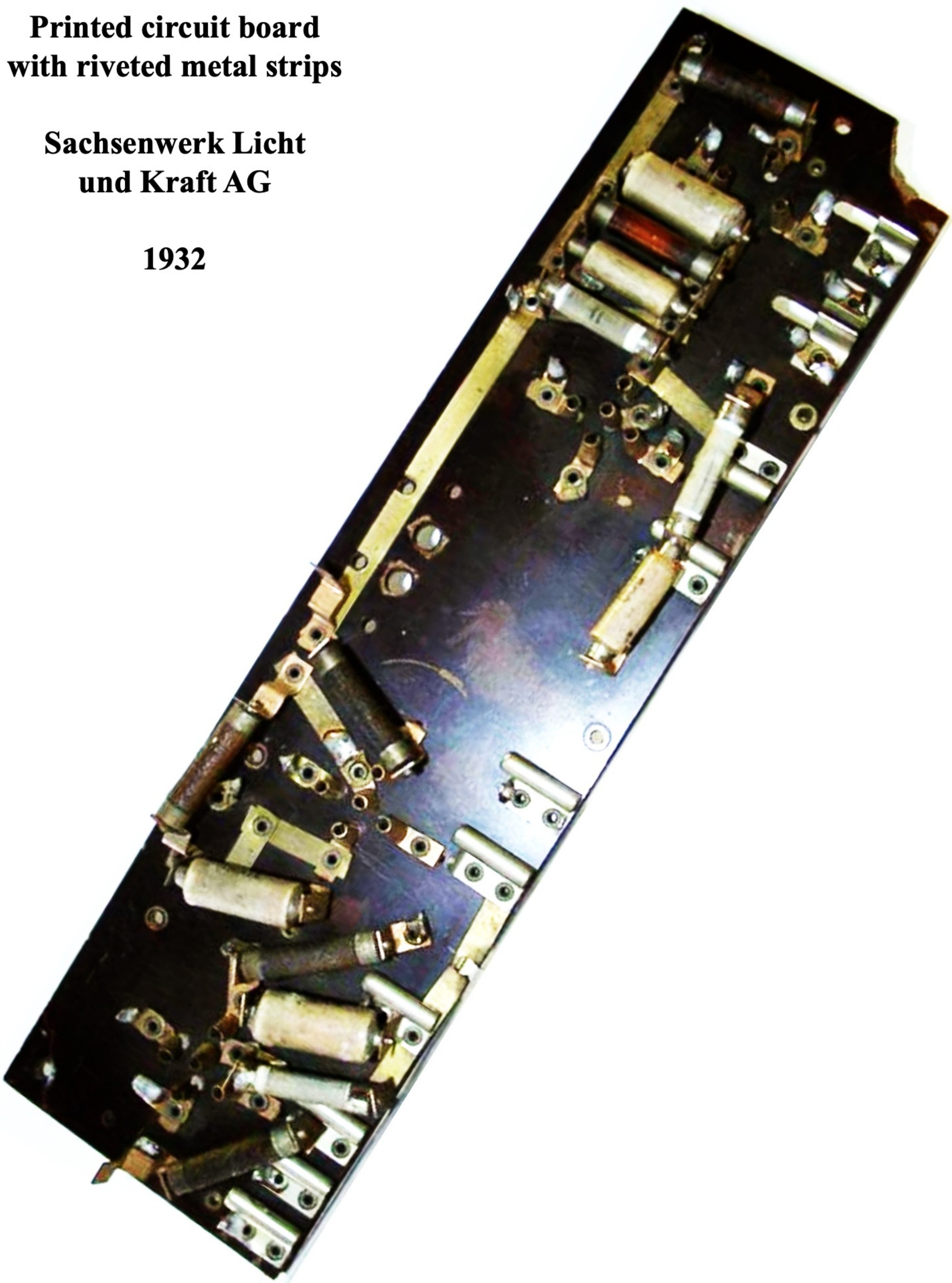


Figure 6.109: Printed circuit board with riveted metal strips, Sachsenwerk Licht und Kraft AG, 1932.

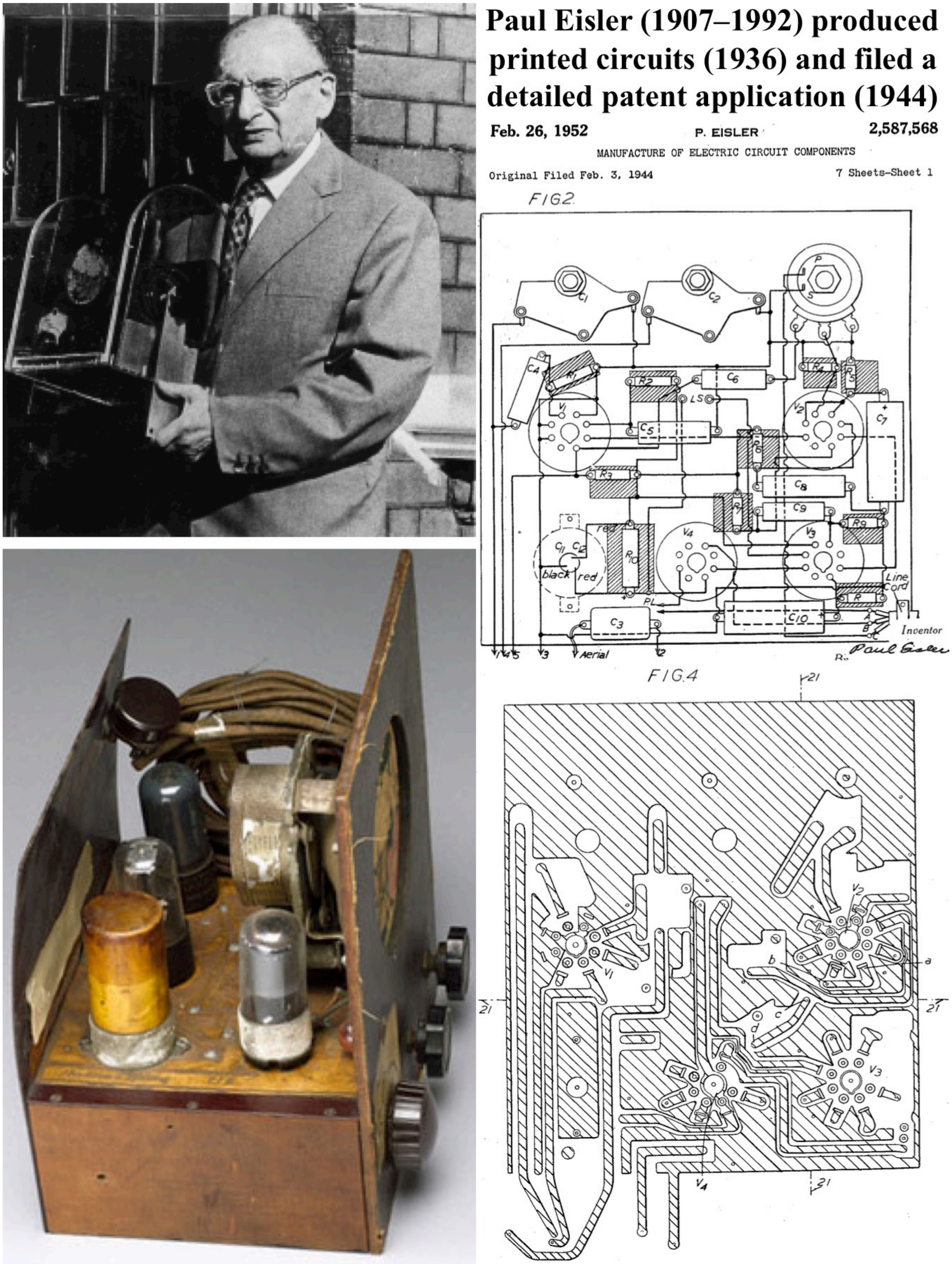


Figure 6.110: Paul Eisler produced printed circuits in 1936 and filed a patent application on them in 1944. At least three German companies produced printed circuits several years before Eisler, and he was presumably familiar with their technology from his studies and work as an electrical engineer in the German-speaking world.

NARA RG 40, Entry UD-75,
Box 25, Folder Odarenko, Dr. T. M.

- 2 -

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"Previously, the chassis were stamped out of sheet metal, and the partitions and supports -- angle arms and the like -- for each of the many components used in a radio or radar set had to be bolted, screwed or welded separately to the chassis", Dr. Odarenko explained. "The casting machine combines all these separate operations into one, conserving time and labor."

A similar German development for expediting the mounting of electronic assemblies was the wide use of ceramic insulating plates with printed or stamped painted or sprayed, and baked in, electrical connections. These reduced or completely eliminated the need for the conventional, laborious wiring, Dr. Odarenko said.

The need for thoroughly studying German technique is also an essential requirement for successfully manufacturing in the States of many ingenious devices and of useful materials developed or invented in Germany in recent years, Dr. Odarenko declared. Frequently, attempts at manufacture proved that careful reading

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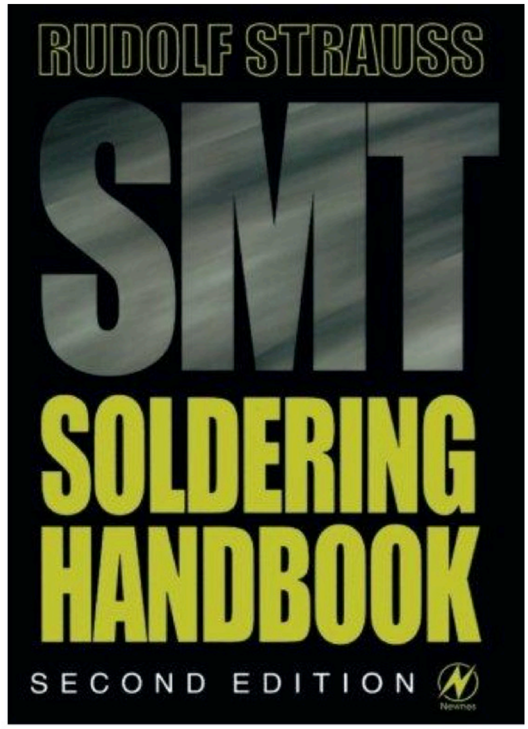
additional detail information from the North German Submarine Cable plant of Nordenham, the company that perfected the conversion process.

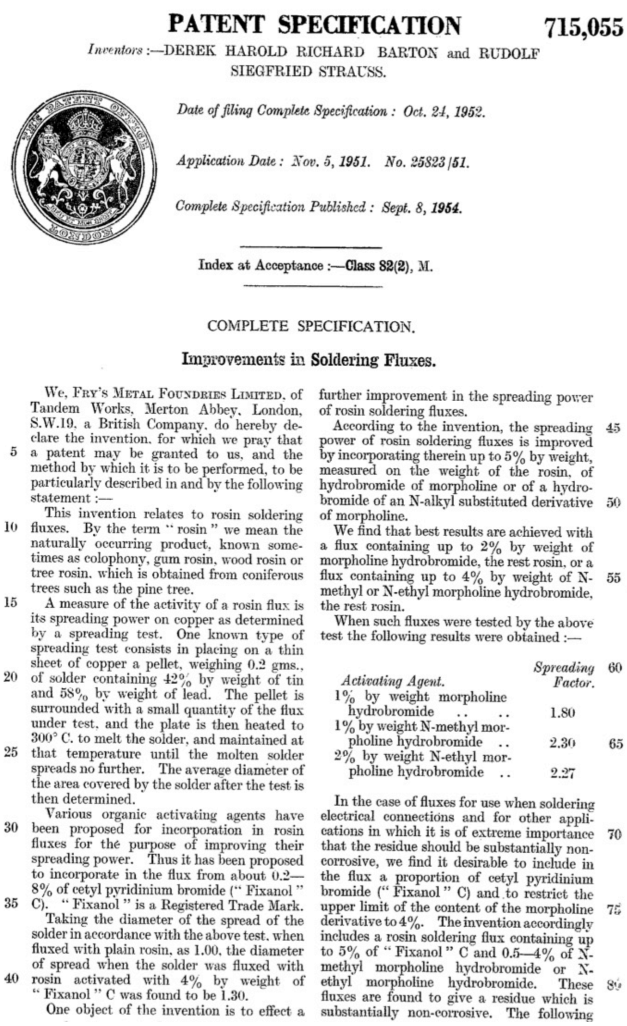
"A little time spent in on-the-spot investigation in Germany before going into production", Dr. Odarenko pointed out, "will more than repay a manufacturer for the expense of sending an investigator to Germany."

Dr. Odaranko spent 4 months in Germany this year and about 6 months last year for the Electronics and Communications Unit of OTS' Technical Industrial Intelligence Division. From 1928 to 1943, he worked as a member of the Technical Staff for the Bell Telephone Laboratories, and prior to joining the staff of the International Telephone and Telegraph Company, he served as a consultant and advisor for the Bureau of Ships of the U.S. Navy and the Radar Division of the War Production Board.

Figure 6.111: Printed circuits were in "wide use" in wartime Germany and the technology was transferred to the United States after the war by people such as longtime Bell Telephone Laboratories engineer Todos Odarenko [NARA RG 40, Entry UD-75, Box 25, Folder Odarenko, Dr. T. M., undated press release (probably late 1946)].

Rudolf Strauss (1913–2001) invented wave soldering for printed circuits, or surface mount technology (1951–1955)





PATENT SPECIFICATION **715,055**

Inventors:—DEREK HAROLD RICHARD BARTON and RUDOLF SIEGFRIED STRAUSS.

Date of filing Complete Specification: Oct. 24, 1952.

Application Date: Nov. 5, 1951. No. 25823/51.

Complete Specification Published: Sept. 8, 1954.

Index at Acceptance:—**Class 82(2)**, M.

COMPLETE SPECIFICATION.

Improvements in Soldering Fluxes.

We, FRY'S METAL FOUNDRIES LIMITED, of Tandem Works, Merton Abbey, London, S.W.19, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to rosin soldering fluxes. By the term "rosin" we mean the naturally occurring product, known sometimes as colophony, gum rosin, wood rosin or tree rosin, which is obtained from coniferous trees such as the pine tree.

A measure of the activity of a rosin flux is its spreading power on copper as determined by a spreading test. One known type of spreading test consists in placing on a thin sheet of copper a pellet, weighing 0.2 gms., of solder containing 42% by weight of tin and 58% by weight of lead. The pellet is surrounded with a small quantity of the flux under test, and the plate is then heated to 300° C. to melt the solder, and maintained at that temperature until the molten solder spreads no further. The average diameter of the area covered by the solder after the test is then determined.

Various organic activating agents have been proposed for incorporation in rosin fluxes for the purpose of improving their spreading power. Thus it has been proposed to incorporate in the flux from about 0.2—8% of cetyl pyridinium bromide ("Fixanol" C). "Fixanol" is a Registered Trade Mark.

Taking the diameter of the spread of the solder in accordance with the above test, when fluxed with plain rosin, as 1.00, the diameter of spread when the solder was fluxed with rosin activated with 4% by weight of "Fixanol" C was found to be 1.30.

One object of the invention is to effect a further improvement in the spreading power of rosin soldering fluxes.

According to the invention, the spreading power of rosin soldering fluxes is improved by incorporating therein up to 5% by weight, measured on the weight of the rosin, of hydrobromide of morpholine or of a hydrobromide of an N-alkyl substituted derivative of morpholine.

We find that best results are achieved with a flux containing up to 2% by weight of morpholine hydrobromide, the rest rosin, or a flux containing up to 4% by weight of N-methyl or N-ethyl morpholine hydrobromide, the rest rosin.

When such fluxes were tested by the above test the following results were obtained:—

Activating Agent.	*Spreading Factor.*
1% by weight morpholine hydrobromide	1.80
1% by weight N-methyl morpholine hydrobromide ..	2.30
2% by weight N-ethyl morpholine hydrobromide ..	2.27

In the case of fluxes for use when soldering electrical connections and for other applications in which it is of extreme importance that the residue should be substantially non-corrosive, we find it desirable to include in the flux a proportion of cetyl pyridinium bromide ("Fixanol" C) and to restrict the upper limit of the content of the morpholine derivative to 4%. The invention accordingly includes a rosin soldering flux containing up to 5% of "Fixanol" C and 0.5—4% of N-methyl morpholine hydrobromide or N-ethyl morpholine hydrobromide. These fluxes are found to give a residue which is substantially non-corrosive. The following

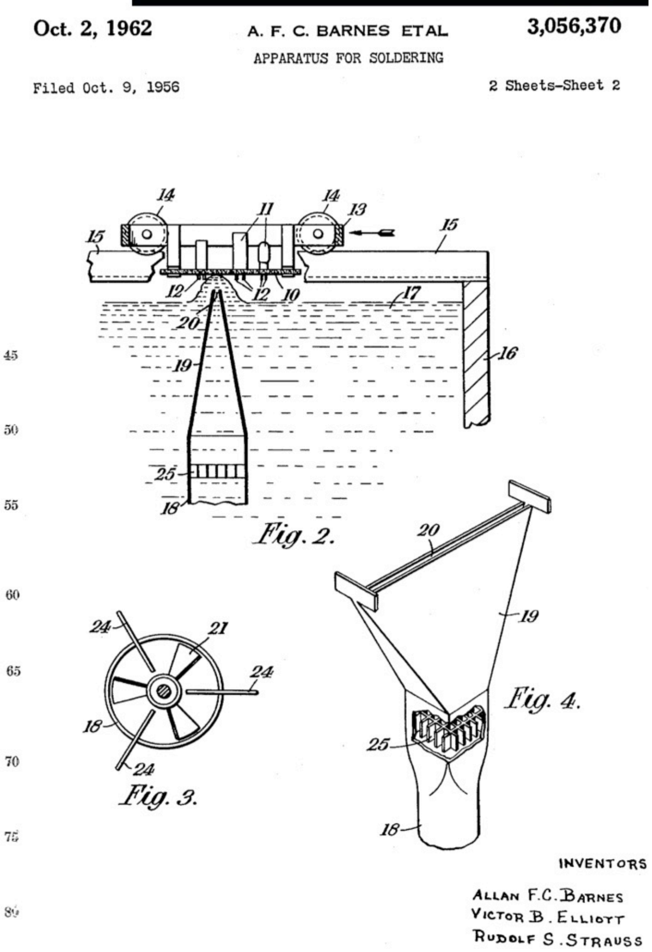


Figure 6.112: Rudolf Strauss developed the wave soldering method for automated manufacturing of printed circuits, or surface mount technology (SMT), from 1951 to 1955.

6.5.7 Integrated Circuits

Even further miniaturization of electronics required moving from individual electronic components to integrated circuit chips that could contain large numbers of components on the same semiconductor substrate.

In 1949, Werner Jacobi (German, 1904–1985) filed a West German patent application on integrated circuits on behalf of Siemens & Halske. Since there were a large number of German inventors who filed patents on their wartime work when the (West) German patent office reopened in 1949, it is quite likely that Jacobi's patent application was based on experimental work that he had conducted at Siemens & Halske during the war (pp. 1105 and 2828–2829).

Kurt Lehovec (Bohemian/Austrian/Czech, 1918–2012) developed advanced semiconductor devices for Germany in Prague during the war. After the war he was extensively interrogated by the United States and then moved to the United States (as part of Operation Paperclip), where he filed patents on transistors, integrated circuits, and light emitting diodes. See pp. 1083, 1106, 2769–2775, 2830–2844, and 2907–2922. Lehovec's integrated circuit designs may well have been based on wartime work, but even if they were early postwar ideas, they preceded the claims of American engineers who later worked on integrated circuits.

Other German-speaking scientists developed transistor fabrication methods that made integrated circuits practical:

- Herbert Kroemer (German, 1928–) invented the drift transistor in 1953 or earlier, the double-hetero-structure laser diode in 1963, and III-V semiconductor heterostructures in 1966 or earlier. See pp. 1120, 2845–2857, and 2929–2934. He won the Nobel Prize in Physics in 2000 (p. 1113).

- Jean Hoerni (Swiss, 1924–1997) and Eugene Kleiner (Austrian, 1923–2003) devised methods of manufacturing silicon transistors at Fairchild Semiconductor; see pp. 1110 and 2858–2873. Through Fairchild and their later companies and investments, they also helped to develop Silicon Valley.

- Karl Heinz Zaininger (German, 1929–) developed modern methods for fabricating field effect transistors (pp. 1111 and 2874–2888).

As shown on pp. 1112 and 2889–2899, Helmut Gröttrup (German, 1916–1981) and Jürgen Dethloff (German, 1924–2002) 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 (pp. 1886–1893).

As with transistors and printed circuits, much more research should be conducted to determine how much work on integrated circuits was conducted in the German-speaking world during the war, and how much impact German-speaking scientists and knowledge had on the postwar development of integrated circuits in other countries.

Werner Jacobi (1904–1985) filed a patent application on integrated circuits in 1949 (based on wartime work?)

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 30. JUNI 1952

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 833 366

KLASSE **21a²** GRUPPE 18₀₈

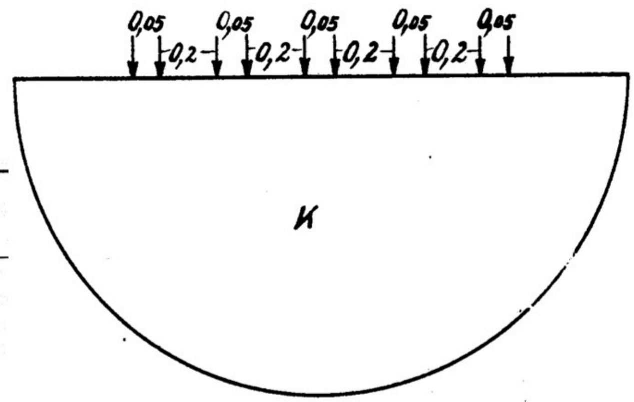
p 2589 VIIIa/21a² B

Dr. phil. Werner Jacobi, Erlangen
ist als Erfinder genannt worden

Siemens & Halske A. G., Berlin und München

Halbleiterverstärker

Patentiert im Gebiet der Bundesrepublik Deutschland vom 15. April 1949 an
Patenterteilung bekanntgemacht am 15. Mai 1952



Wenn der Halbleiter in der zur Zeit bekannten Form vielleicht auch nicht geeignet ist, in allen Fällen von Verstärkeranordnungen an die Stelle einer Elektronenröhre zu treten, so scheint seine Anwendung jedoch für bestimmte Zwecke vorteilhaft zu sein. So dürfte er sich u. a. besonders für Schwerhörigengeräte eignen. Aus dieser Zweckbestimmung heraus entsteht die Aufgabe, deren Lösung selbstverständlich auch für jegliche andere Anwendung des Halbleiterverstärkers grundsätzliche Bedeutung z. B. aus preislichen Gründen hat, einen solchen Halbleiterverstärker nicht nur billig, sondern auch raum-, gegebenenfalls auch gewichtssparend aufzubauen. Zur Lösung dieser Aufgabe wird erfindungsgemäß vorgeschlagen, auf den Halbleiter mehrere in verschiedenen Schalt- bzw. Verstärkerstufen wirkende Elektrodensysteme aufzusetzen.

Nimmt man z. B. an, daß der in der Figur als geschnittene Halbkugel gezeigte Halbleiter K einen Durchmesser von 2 mm hat, so können je nach der konstruktiven Gestaltung und Anordnung der einzelnen Elektroden mehrere Elektrodensysteme in je einem Abstand von 0,2 mm bei bekanntem Elektrodenabstand von 0,05 mm aufgesetzt werden, ohne daß eine gegenseitige Beeinflussung der einzelnen Systeme eintritt. Diese Elektrodensysteme können dann in bekannter Weise durch Kopplungsglieder zu einem mehrstufigen Halbleiterverstärker zusammengeschaltet werden.

Hierbei können die Kopplungsglieder gegebenenfalls aus einer Halbleiteranordnung bestehen, welche zusätzlich aufgewendet oder durch Einsatz von auf den Halbleiter schon aufgesetzten Elektrodensystemen gebildet werden. Zu diesem Zweck wird die sonst als Eingang dienende Elektrode als Ausgang des Kopplungsgliedes benutzt und umgekehrt, da der Halbleiterverstärker einen niederohmigen Eingang und einen hochohmigen Ausgang benötigt. Man erspart also auf Grund der vorliegenden Erkenntnis, den Halbleiter mit vertauschtem Eingang und Ausgang als Transformator zu benutzen, mit Rücksicht auf diese Eingangs- und Ausgangsverhältnisse besonders auszubildende Kopplungsglieder. In der Figur sind fünf solcher Systeme mit den beispielsweise einzuhaltenden Maßen schematisch angedeutet.

PATENTANSPRÜCHE:

1. Halbleiterverstärker, dadurch gekennzeichnet, daß auf den Halbleiter mehrere in verschiedenen Schalt- bzw. Verstärkerstufen wirkende Elektrodensysteme aufgesetzt werden.
2. Halbleiterverstärker, insbesondere nach Anspruch 1, dadurch gekennzeichnet, daß bestimmte Elektrodensysteme nach Vertauschung von Eingangs- in Ausgangselektrode und umgekehrt als Kopplungsglieder zwischen anderen Elektrodensystemen dienen.

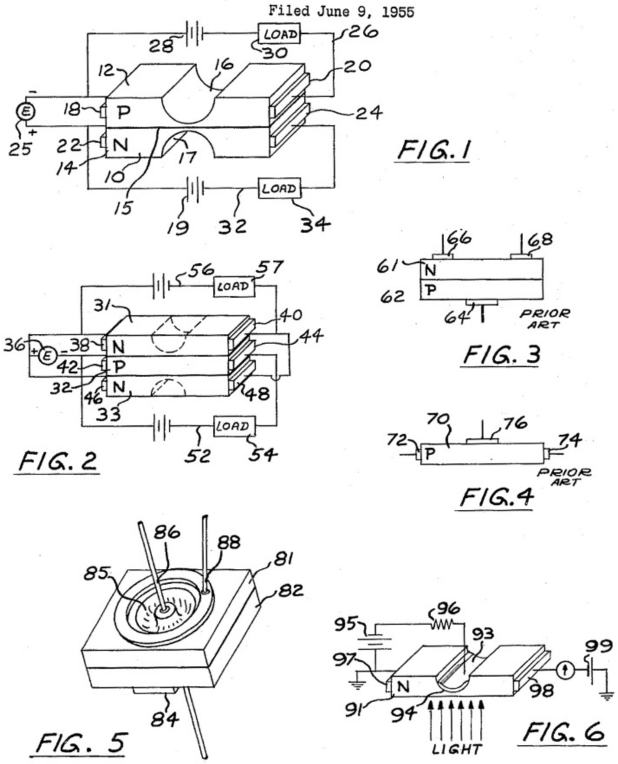
Figure 6.113: Werner Jacobi filed a patent on integrated circuits in 1949, likely based on wartime work.

Kurt Lehovec (1918–2012) created integrated circuits (based on wartime work with Bernhard Gudden?)

July 25, 1961 K. LEHOVEC 2,993,998

TRANSISTOR COMBINATIONS

Filed June 9, 1955



United States Patent Office 2,993,998 Patented July 25, 1961

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2,993,998

TRANSISTOR COMBINATIONS

Kurt Lehovec, Williamstown, Mass., assignor to Sprague Electric Company, North Adams, Mass., a corporation of Massachusetts

Filed June 9, 1955, Ser. No. 514,220

5 Claims. (Cl. 250—211)

This invention relates to transistor combinations, more particularly to combinations by which signals can be amplified.

Among the objects of the present invention is the provision of novel transistor combinations which have improved amplification characteristics as compared to prior art combinations.

The above as well as additional objects of the present invention will be more clearly understood from the following description of several of its exemplifications, reference being made to the accompanying drawings wherein:

FIG. 1 is a representative showing, partly in schematic form, of one embodiment of a unipolar transistor;

FIG. 2 is a schematic showing of a modified unipolar transistor combination according to the present invention;

FIGS. 3 and 4 are diagrammatic views of prior art forms of unipolar transistors; and

FIGS. 5 and 6 are pictorial representations of modified unipolar semiconductor devices according to the invention.

A unipolar transistor was fully described by W. Shockley in an article, entitled "A Unipolar Field Effect Transistor," which appeared in the November 1952 issue of the Proceedings of the IRE, Volume 40, No. 11, pages 1365–1376. Briefly the device consists essentially of a semiconductor having a conducting channel with an adjacent equipotential layer or gate electrode and a space charged region in the semiconductor between the channel and the equipotential layer. By varying the potential between the channel and the equipotential layer, the effective channel width can be varied and the channel current which is being carried therein is similarly varied. When the current flows along the channel the potential thus varies along the channel, which in turn results in a potential variation between the channel and the equipotential layer. As a result, the width of the space charged region varies along the channel and with sufficiently high potentials imposed on opposite ends of the channel, the space charged region may extend completely over the channel rendering it insulating or may even cause breakdown if maintained. This limits the usefulness of the device. It is thus the intent of this invention to render these unipolar field effect transistors less susceptible to breakdown or alternatively, susceptible to much higher current gain, as well as reliability of operation when used with signal voltages of substantial amplitudes.

It has been found possible to improve the operating curve of the unipolar transistor so as to handle larger signal voltages as well as to produce much higher power gains, through provision of two parallel current flows in a unipolar transistor so as to maintain the width of the charged layer at a uniform dimension. This is readily accomplished as indicated by providing a potential drop along the gate electrode which is the same or similar to the voltage drop along the channel.

For better understanding of this invention refer to FIG. 1, wherein the combination here illustrated has a semiconductor body **10** with two portions **12**, **14** of opposite types of conductivity. Portion **12**, for example, is indicated as having p-conductivity and portion **14** n-conductivity. Between them there is a p–n junction **15** that is relatively elongated. Intermediate of the ends of the rectangular crystal **10** are two depressions **16** and **17**, the

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former extending down into the p-region of conductivity and the latter extending into the n-region of conductivity. These grooved areas extend fully across the face of the crystal and are readily produced by magnetostrictive cutting followed by a jet electrochemical etch, both techniques of which are well-known to the art. The thickness of the web formed in the crystal between the points of maximum depth of depressions **16** and **17** is preferably very thin, not over 20 mils thick, and preferably much thinner, in the order of 2 mils thickness. Of course, it is to be realized that this lower limit of distance between the two depressions is dictated by the structural strength requirements which the device must exhibit. However, for optimum operational characteristics the thin region separation is desirable although the crystal can readily be supported by outside insulators, such as plastic holders, etc.

At opposite ends of each portion **12**, **14** are positioned electrodes represented at **18**, **20**, **22**, **24**. A bias supply **25** is connected between a correspondingly located pair of electrodes **18**, **22**, on the respective semiconductor portions, to bias the portions in the direction that blocks the passage of current from one body to the other. In the construction of FIG. 1 the bias supply also impresses varying signals "E" between the same electrodes **18**, **22**.

Electrodes **18**, **20** are shown as connected to an output circuit **26** including a source of potential **28** and an output load **30**. Another output circuit **32** is similarly connected between electrodes **22** and **24** and similarly polarized. For purposes of discussion the n-conductivity having electrodes **22** and **24** is designated the "channel" while the p-region with its electrodes **18** and **20** is designated the "gate."

The entire combination of FIG. 1 makes a so-called unipolar transistor amplifier in which the junction **15** provides a space charge effect that is substantially uniform along its length. For the greatest uniformity the semiconductor portions **12**, **14** should have corresponding electrical resistivities, e.g. of the order of 5 ohm-centimeters, and the output circuits should be arranged to apply corresponding potentials so that there are corresponding potential gradations along the effective length of the junction in both the channel and gate portions. The resistivities are controlled by the concentration of doping ingredients added to the respective semiconductor bodies either by diffusion into the solid body, surface melting or by alloying with a liquefied mass from which the bodies are formed.

A feature of the construction of FIG. 1 is that two different amplified output signals are provided so that one can be used independently of the other as a monitor, for example. In addition, where maximum power output is desired, both output signals can be combined as by transformer coupling. This is made possible by the use of the two depressions **16** and **17** so that the dimension of the space charge region could materially effect the current flow in the channel. Herein, in FIG. 1, for one part of the circuit including load **30** the n-region is the channel and the p-region the gate, and for the other part of the circuit including load **34**, vice versa.

FIG. 2 shows a modified construction of the unipolar transistor type in which one region of conductivity is sandwiched between regions of opposite conductivity. The three regions are illustrated as **31**, **32**, **33**, being produced by techniques well-known in the art. Blocking bias, as well as incoming signals, are supplied by source **36** between the intermediate body **32** on the one hand, and the outer two which can be connected together. Electrodes **38**, **40**, **42**, **44**, **46** and **48** are provided on the individual bodies as in the construction of FIG. 1.

The junction construction of FIG. 2 also has two output circuits **52**, **56**. One of these is connected to inter-

2,993,998

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mediate body **32** as in the construction of FIG. 1. The second output circuit **56** is connected to both outer bodies **31**, **33** in parallel. As a result of this construction, signals in the sandwiched body are subjected to what corresponds to two space charge effects, one at each junction. The voltage amplification of this body will therefore be larger than that of the others. Moreover, signal currents in the outer bodies can be added together by the parallel output connection.

With the construction of FIG. 2 the amplified output is taken from load **54** while load **57** serves merely to maintain the space charge region relatively constant along the junction. For taking a useful output from both loads **54** and **57** depressions similar to those of FIG. 1 must be imposed in the n-regions **31** and **33** completely across the opposing faces of the crystal.

FIGS. 3 and 4 are cross-sectional representations of known prior art devices of the unipolar field effect type. In FIG. 3 the n-region designated as **61** has two electrodes **66**, **68** between which an output circuit can be connected. Bias, as well as incoming signals, are supplied between electrode **64** and one of the electrodes **66**, **68** using the p-region to produce the gate and the n-region as the channel. In this construction, as well as the construction shown in FIGS. 1 and 2, all of the electrodes are of a non-rectifying nature.

In FIG. 4, however, an area metal contact which extends fully across the width of the crystal is utilized to produce a space charged region which can thus serve as the modulating means for the current flow in the channel. A semiconductor body **70** designated for the purposes of this discussion as having a conductivity of the p-type has spaced output electrodes **72** and **74** of the non-rectifying kind and an intermediate electrode **76** of the rectifying metal type. Thus a space charge effect similar to that described above appears to be provided by the metal electrode **76** when it is electrically biased in the current blocking direction. The bias and the incoming signals are impressed between the metal electrodes **76** and one of the other electrodes. Amplified output signals can be taken thus from between electrodes **72** and **74**. The construction of FIG. 3 is susceptible to breakdown at pinch-off because here, as well as in the Shockley discussion, the space charged region is non-uniform with the junction area. Breakdown additionally may occur rendering the device conducting so that the FIG. 4 construction is limited both in current level, as well as amplification characteristics.

In FIG. 5 is shown an embodiment of the invention constituting an improvement of the unipolar transistor construction shown in FIG. 3. This construction somewhat similar to that of FIG. 3 has a first semiconductive region **81** and a second semiconductive region **82**, the regions having opposite types of conductivity so that a junction exists between them. Output electrodes are illustrated in the form of a central non-rectifying electrode **86** engaging body **81**, and a circular non-rectifying electrode **88** surrounding electrode **86**. Between the two electrodes **86**, **88** is produced an annular depression **85** extending into body **81** in order to increase the amplification effect of the device. The depth of the depression should be such as to approach the junction region, e.g. less than 5 mils therefrom. The use of a rotating etch jet as described in the above-identified patent application, Serial No. 460,835 (abandoned), makes a very convenient technique for the annular cutting operation. A suitable biasing electrode of the non-rectifying type can be provided as indicated, for example, at **84**. Using this technique allows close control of the distance between the junction and bottom of cut.

Of course, it is to be understood that where even higher amplification is desired or where it is desired to increase the useful current ranges of the device, thus requiring complete avoidance of the breakdown in the pinch-off region resulting from the non-uniformity of the space

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charged region, the construction of FIG. 5 is modified to conform to the concept of FIG. 1. This is readily accomplished by imposing a second annular groove on the opposite surface of the crystal of FIG. 5, namely that surface whereon electrode **84** is shown to be imposed.

Instead of applying the bias to the same electrodes by which the input signals are impressed, other electrodes can be used. In the construction of FIG. 1, for example, bias can be provided between electrodes **18** and **22**, whereas the input signals can be applied between electrodes **20** and **24**. A similar arrangement can be used in the construction of FIG. 2. Furthermore, the bias need not be applied between correspondingly located electrodes, and can be impressed between electrodes **18** and **24**, for example. The incoming signals can also be applied in this manner.

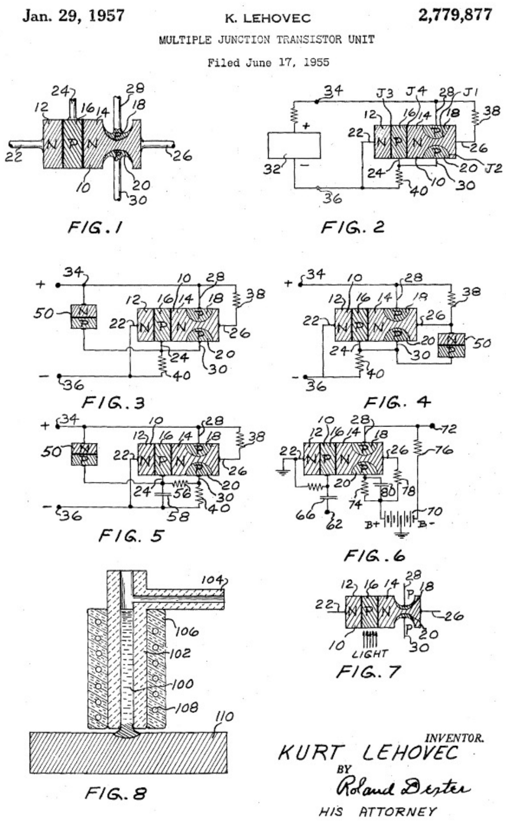
FIG. 6 shows a further form of unipolar transistor construction most useful as a photosensitive device in which the bulk of the crystal **91** is of one conductivity, e.g. n-type, however a diffused junction exists at the region of the depression. In the depression there is an electrode **93**, and at opposite edges of the crystal are non-rectifying electrodes **97**, **98**. The electrode **93** and one of the other non-rectifying electrodes **97** are connected to a high impedance bias source shown as a resistive impedance **96** and a voltage source or battery **95**. When the body **91** of such material is exposed to incident light, current flows across the web between electrode **93** adjacent the irradiation site and the crystal **91**. This current flow reduces the bias imposed by the battery **95** through resistor **96**. Thus the space charge in body **91** adjacent to electrode **93** is reduced allowing greater flow of current in the channel between non-rectifying electrodes **97**, **98**.

The voltage source **95** biases the electrode **97** in the current-blocking direction. With the impedance **96** relatively low as compared to the blocking impedance of the un-illuminated junction, the potential of source **95** is essentially entirely impressed across this junction **94**. When irradiation takes place, the impedance of the junction is sharply diminished so that the potential across the junction **94** is greatly lowered. The lowering of the potential across the blocking junction causes a corresponding amplified change in the current passed between output electrodes **97**, **98** as a result of the decrease of the space charge region. The photoelectric output of the construction of FIG. 6 will accordingly be much higher than that conventionally obtained from present devices, and has a sensitivity to radiation which is remarkable.

Although it is to be fully understood that the following specific examples are representative of the best constructions known to us, they should not in any way limit the scope of the instant invention. Reference should now be made to the drawing of FIG. 1 wherein in its preparation one would take a rectangular slab of p-n junction crystal produced by surface melting techniques or other techniques known to the art, and properly dimension the crystal as follows: The crystal could be a cube of 100 mils in each dimension with the junction region substantially in the center of the plane of the cube. Such a crystal would be of germanium and have for the p-impurity indium and for the n-impurity antimony, with each region of conductivity having a resistivity in the order of 5 ohm-centimeters. As indicated above, such a crystal could be produced by any of the known techniques including the surface melting technique fully disclosed in the copending application of Lehovec et al., Serial No. 364,138, filed June 25, 1953 (abandoned). The depressions **16**, **17** should be then imposed across the opposing faces of the crystal first by magnetostrictive cutting with an appropriate tool, which technique is fully disclosed in United States Patent No. 2,580,716. The width of this cut would be approximately 15 mils and extend with vertical sides down to the region adjacent to the junction. After the magnetostrictive cutting has produced a depression of

Figure 6.114: Kurt Lehovec created integrated circuits (based on wartime work with Bernhard Gudden?).

Kurt Lehovec created integrated circuits (based on wartime work with Bernhard Gudden?)



United States Patent Office

2,779,877
Patented Jan. 29, 1957

1

2,779,877

MULTIPLE JUNCTION TRANSISTOR UNIT

Kurt Lehovec, Williamstown, Mass., assignor to Sprague Electric Company, North Adams, Mass., a corporation of Massachusetts

Application June 17, 1955, Serial No. 516,188

4 Claims. (Cl. 250—211)

This invention relates to semiconductor signal translating devices and more particularly to bi-stable circuits which include a novel semiconductive device.

Bi-stable circuits that include transistors of the junction type form the subject matter of United States Patent No. 2,655,609, issued October 13, 1953. This patent is concerned with the use of a pair of symmetrical multiple junction transistors associated so as to constitute a composite circuit element having novel advantageous characteristics as a switching structure readily transferable from the open circuit to the closed state upon application of a voltage of prescribed amplitude between the input terminals. The individual transistors used have to be protected carefully against the influence of the operational enviroment by hermetic sealing. This requirement of hermetic sealing necessitates a housing requiring a substantially greater volume than that volume demanded by the physical configuration of the transistor itself. Further, to be satisfactory, the operational characteristics of the two transistors must be carefully matched for incorporation into the circuit.

One general object of this invention is therefore to produce multiple junction semiconductor crystals suitable for bi-stable circuits. A more specific object of this invention is production of a fused junction by a novel process. Other objects will be apparent from the following paragraphs and appended drawings.

Briefly, the objects of this invention have been achieved by the production of a semiconductive crystal of the symmetrical multiple grown junction type which further has at least two fused junction regions integrated into one conductivity region of the multiple junction.

In a more limited sense, the objects of this invention have been achieved by the production of a signal translating device which comprises a semiconductive crystal of the symmetrical multiple grown junction type having at least two fused junctions with electrodes secured respectively to the intermediate section of said multiple grown junction, the two said fused junctions and the end regions of said multiple grown junction.

The invention and the other features noted above will be understood more clearly and fully from the detailed description with reference to the accompanying drawings in which:

Fig. 1 is a cross-sectional view of the grown and fused junction semiconductor element of the invention;

Fig. 2 is a diagram representing a circuit embodiment of utilizing the device of the invention;

Figs. 3, 4 and 5 depict other circuitry including both Zener diodes and the device of the invention;

Fig. 6 illustrates an amplifier circuit using the single transistor of the invention;

Fig. 7 pictures a cross-sectional view of a light responsive signal translating device; and

Fig. 8 is a cross-sectional view of an apparatus for imposing the fused junction regions onto the surface of the multiple grown junction crystal.

Referring now to the drawings, Fig. 1 shows a cross-

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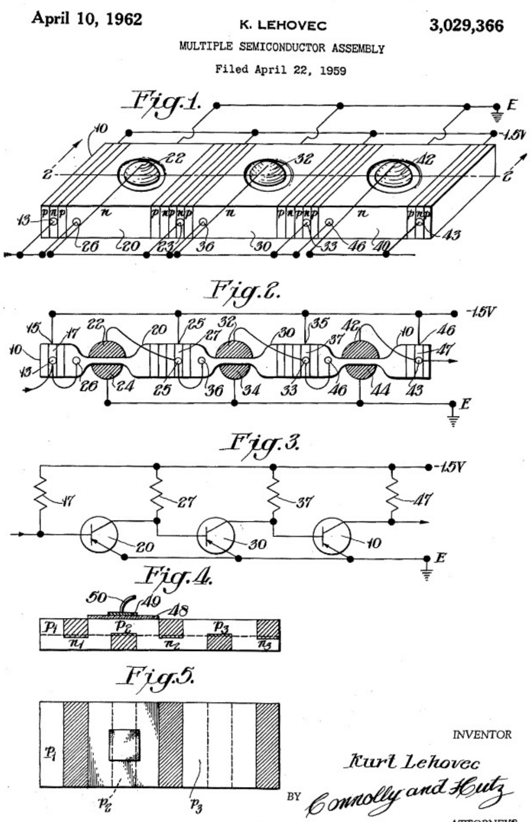
section of a semiconductive structure which replaces two of the transistors previously required for bi-stable circuits. The crystal 10 is monocrystalline and of germanium or silicon appropriately doped with impurities so as to effect symmetrical multiple junctions of the n-p-n or p-n-p types. Herein is shown a grown n-p-n crystal having the n-regions designated 12 and 14 and the p intermediate region as 16. At one end of the crystal there are imposed two regions 18 and 20 of p conductivity produced as fused junctions. It is thus seen that there is in one crystal an n-p-n body which in turn finds one of the regions of n conductivity serving as the intermediate conductivity region for a p-n-p junction crystal. Appropriate non-rectifying electrodes 22, 24, 26, 28 and 30 are attached to the crystal shown in Fig. 1. For best operation the crystal 10 has surface depressions in which the fused junctions are produced so as to limit the thickness of the intermediate n region. For certain applications it is not necessary to have the non-rectifying electrode 26 present.

In Fig. 2 which shows an elementary circuit application of the device of the invention the source 32, poled as shown in the drawing, is connected between the terminals 34 and 36 of the composite crystalline body. The terminals 34 and 36 may be, for example, the cross points in telephone switching systems. The polarity of the source 32 is such that at least one reversed biased junction is included in every current path that can be traced between the terminals 34 and 36 through the composite multiple junction crystal 10. Thus, as shown, the junctions J-2 and J-4 are biased in the reverse or high resistance direction, at least one of which junctions is included in any current path through the combination. The operating state with such a polarity is thus the high impedance or low current condition. Upon increase of the voltage between the terminals 34 and 36 the currents passed by the reversely biased junctions J-2 and J-4 will increase changing the bias across J-1 and J-3 which is a function of the current flow through resistors 38 and 40. At a certain potential the circuit will change to a high current or conduction condition which state obtains when the resistances of the crystal approach those of resistors 38 and 40. Thus the circuit may be triggered from a substantially open circuit (low current) state to a closed circuit (high current) state by the application of voltage of a necessary magnitude between the terminals 34 and 36.

In certain applications it is desirable to determine the point at which the circuit will trigger at a present value. This is readily accomplished by modification of the circuit of Fig. 2 to that of Figs. 3, 4 and 5 by the utilization of a semiconductor junction diode 50, for example, germanium or silicon, which is connected in series with resistor 40 between the terminals 34 and 36. Therefore in Fig. 3, when the voltage between the terminals 34 and 36 rises to such a level as to establish the Zener voltage across the diode, the resulting large current which flows through both resistors 38 and 40 produces such biases on the respective emitters of the composite transistor element to transfer the condition from a low current to a high current level. The preparation of such Zener diodes is readily accomplished by surface melting of a crystal of given impurity, doping the melt with an impurity which produces a body of opposite conductivity and solidifying. The Zener voltage is a function of the conductivity of the crystal and can thus be fabricated for a given voltage of up to 100 volts or greater. In both Figs. 2 and 3, after the device is triggered to the high current or closed circuit conditions, it remains in that condition until the voltage between the terminals 34 and 36 is reduced to substantially 0. For ease of discussion the designation of the elements is common for Figs. 2, 3, 4 and 5. In



United States Patent Office

3,029,366
Patented Apr. 10, 1962

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3,029,366
MULTIPLE SEMICONDUCTOR ASSEMBLY
Kurt Lehovec, Williamstown, Mass., assignor to Sprague Electric Company, North Adams, Mass., a corporation of Massachusetts
Filed Apr. 22, 1959, Ser. No. 808,249
7 Claims. (Cl. 317—101)

This invention relates to a multiple semiconductor assembly, and more particularly to a plurality of semiconductive devices produced on a single semiconductor slice. Still more particularly, this invention relates to the micro-miniaturization of semiconductor assemblies by the preparation of several transistors and related devices on a single semiconductor slice, and the utilization of the resistive and capacitive properties of regions in that slice.

The present day miniaturization of electronic components has reached a state of art that may now be termed "micro-miniaturization," which may be defined as the assembly of a plurality of complementary components in an extremely small volume. Considerable activity has been expended in micro-miniaturizing circuits in which a plurality of transistors is employed. This micro-miniaturization activity has included the concept of direct coupling between stages of some particular types of transistors; e.g., surface-barrier and alloy-junction transistors have properties that permit their use in so-called common-emitter configurations in which the voltage at the collector of one transistor may be high enough to cause saturation at the base of the next transistor in the circuit. An article entitled, "Directly Coupled Transistor Circuits" by R. H. Beter, W. E. Bradley, R. B. Brown and M. Rubinoff, which was published in Electronics for June 1955, discloses the concept of employing a common-emitter transistor amplifier having more than one base connected to a single collector. Others in the art have suggested processes for producing a plurality of p-n junctions in a single semiconductor body; e.g., G. K. Teal U.S. Patent 2,727,840 and R. N. Hall U.S. Patent 2,822,308. However, great difficulty has been experienced in reaching the objective of a generally acceptable multi-transistor assembly on a single semiconductor body, because transistors so-produced have been electrically connected through the semiconductor slice. For example, in transistors of the alloy-junction type wherein the semiconductor slice of homogeneous impurity concentration represents the base of the transistor, all transistors in a multi-transistor assembly are connected to a common base, which is not a desirable configuration for many circuit applications.

A further example of the restricted nature of prior art multi-transistor assemblies is found in my U. S. Patent 2,779,877 issued January 29, 1957, which discloses and claims a signal translating device comprising a semiconductive crystal of the symmetrical grown junction type having two fused junctions disposed inwardly from opposed surfaces of the crystal.

It is an object of this invention to overcome these and other deficiencies of the prior art.

It is a further object of this invention to produce an assembly having a plurality of semiconductive components on a single semiconductor slice, and to provide a sufficient degree of electrical insulation between these semiconductive components through the semiconductor slice so as to permit a circuit designer to have substantial freedom in the interconnection of the components.

It is a still further object of this invention to produce an assembly having a plurality of transistors together with other components such as capacitors, resistors and diodes on a single semiconductor slice.

These and other objects of this invention will become more apparent upon consideration of the following de-

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tailed description when read in conjunction with the accompanying drawing, wherein:

FIGURE 1 is a diagrammatic perspective view of a multiple semiconductor assembly constructed in accordance with this invention, with electrical circuit wiring attached thereto to accomplish the circuit shown in FIGURE 3;

FIGURE 2 is a diagrammatic cross-section of the multiple semiconductor assembly taken along line 2—2 in FIGURE 1; in order to establish a clearer picture of the electrical interconnection of the various semiconductive components, FIGURE 2 is not a true cross-section of FIGURE 1, in that the contacts at the front surface of the assembly of FIGURE 1 have been shown again on the diagrammatic cross-section of FIGURE 2, although it should be understood that these contacts are not in the plane 2—2 of FIGURE 1;

FIGURE 3 is a schematic diagram of a chain of direct coupled amplifiers which may be assembled on a single semiconductor slice of the configuration shown in FIGURE 1 in accordance with this invention;

FIGURE 4 is a diagrammatic cross-sectional view through a multiple region semiconducting slice such as may be used in the construction of another embodiment of the multiple semiconductor assemblies according to this invention; and

FIGURE 5 is a diagrammatic plan view of the multiple region semiconductor slice of FIGURE 4.

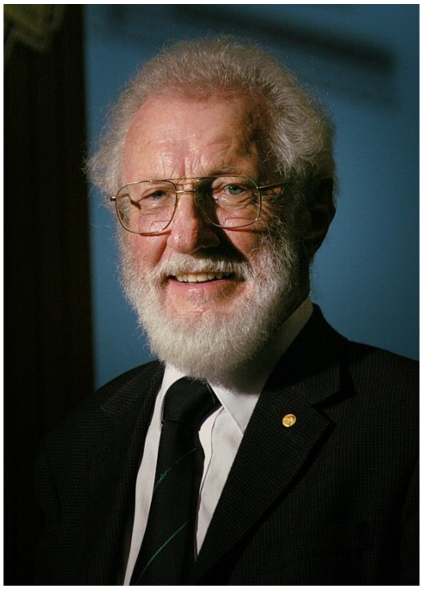
In general, the objects of this invention are attained by a multiple semiconductor assembly in which a plurality of semiconductor components are prepared on the same semiconductor slice in such a manner as to ensure electrical separation of the terminals of the individual semiconducting components. Since these semiconducting components will be transistors in many cases, the following description will be directed specifically to transistors although the concept of the invention applies also to other components, such as capacitors, resistors and diodes.

More particularly the objects of this invention are attained by utilizing a semiconductor slice having a series of p-n junctions that are so constructed and arranged that a transistor may be produced on each of a plurality of regions that are separated from one another by at least one additional p-n junction.

It is well known that a p-n junction has a high impedance to electric current, particularly if biased in the so-called "blocking direction," or with no bias applied. Therefore, any desired degree of electric insulation between two components assembled on the same slice can be achieved by having a sufficiently large number of p-n junctions in series between the two semiconducting regions on which said components are assembled. For most circuits, one to three p-n junctions will be sufficient to achieve the desired degree of insulation. These p-n junctions may be placed quite closely to each other. However, it is often required that they are placed sufficiently far apart from each other that the multiple p-n junction structure used for electric insulation should not act as an active semiconducting element such as a transistor or a four-layer npnp diode. In order to assure this condition, it is required that the region between two junctions is wider than a small multiple of the diffusion length of the minority carriers in said region. The diffusion length is the square root of the diffusion constant multiplied by the lifetime of these minority carriers. For instance, assuming a diffusion constant of 40 $cm.^2$ per second and a lifetime of 1 microsecond, a diffusion length of 60×10^{-4} cm. or approximately 2 mils results, and a separation of 4 mils between the two junctions will be sufficient to avoid any appreciable interaction by carrier injection between the two junctions delineating said region.

In a restricted form of this invention, the objects are attained by a multiple transistor assembly comprising a

Figure 6.115: Kurt Lehovec created integrated circuits (based on wartime work with Bernhard Gudden?).



Herbert Kroemer (1928–) invented drift transistors (1953 or earlier)

Int. Cl.: H 01 l

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DEUTSCHES PATENTAMT

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Anmelder: Siemens AG, 1000 Berlin und 8000 München; Allgemeine Elektricitäts-Gesellschaft AEG-Telefunken, 1000 Berlin und 6000 Frankfurt

Vertreter: —

Als Erfinder benannt: Krömer, Dr. Herbert, Princeton, N. J. (V. St. A.)

Für die Beurteilung der Patentfähigkeit in Betracht gezogene Druckschriften:
DT-PS 868 354
»Das Elektron«, Bd. 5 (1951/52), S. 436

1 414 089

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Die Störstellenkonzentration ist in der Basiszone eines üblichen Flächentransistors praktisch konstant, so daß dort kein elektrisches Feld herrscht. Die vom Emitter herkommenden Minoritätsladungsträger können also nur durch reine Diffusion zum Kollektor gelangen. Dieser Flächentransistor ist also ein »Diffusions-Transistor«. Die Anwendung desselben ist gegenüber derjenigen des Spitzentransistors durch die wesentlich niedriger liegende Frequenzgrenze beschränkt.

In der Patentanmeldung P 13 01 862.7-33 (deutsche Auslegeschrift 1 301 862) ist bereits ein Verfahren zum Herstellen eines Drifttransistors angegeben, das darin besteht, daß eine oder mehrere Störstellenarten in die Basiszone von der Emitterseite so eindiffundiert werden, daß die Störstellenkonzentration an der Emitterseite der Basiszone mindestens zehnmal größer als an der Kollektorseite der Basiszone ist. Es ist dort auch bereits hervorgehoben, daß es bei einem solchen Drifttransistor besonders vorteilhaft ist, die Störstellenkonzentration vom Emitter zum Kollektor monoton abklingend verlaufen zu lassen, wobei die Abnahme an der Emitterseite stärker ist als an der Kollektorseite, so daß der 2. Differentialquotient der Kurve der Störstellenkonzentration überwiegend positiv ist. Beispielsweise kann die Störstellenkonzentration etwa rein exponentiell abfallen. In der Baziszone herrscht dann wegen der räumlichen Konstanz der Fermischen Grenzenergie ein ungefähr konstantes elektrisches Feld, welches die Minderheitsträger zwangläufig zum Kollektor hintreibt. Dies hat zur Folge, daß die oberste Grenzfrequenz des Transistors ansteigt.

Die Erfindung betrifft einen Drifttransistor, bei dem das elektrische Feld in der Basiszone des Transistors erfindungsgemäß dadurch erzeugt wird, daß die Halbleitergrundsubstanz selbst ein nichtstöchiometrischer Mischkristall verschiedener Halbleitermaterialien mit verschiedenen Bandabständen ist, wobei sich die Zusammensetzung des Mischkristalls innerhalb der Basis derart ändert, daß die Bandbreite von der Emitter- zur Kollektorseite monoton abnimmt, während der Leitfähigkeitstyp unverändert bleibt. Auf diese Weise läßt sich ein noch höheres Driftgefälle und damit eine noch stärkere Verbesserung der Frequenzgrenze erzielen.

Gegebenenfalls kann zusätzlich zu der Bandbreitenvariation die Störstellenkonzentration des Halbleitermaterials vom Emitter zum Kollektor monoton abnehmen. Dabei ist zweckmäßig die Feldstärke, die durch das Zusammenwirken von Störstellen- und Bandbreitenvariation entsteht, möglichst homogen zu machen. Diese Maßnahmen können zu einer weiteren Steigerung des Driftgefälles und damit zu einer weiteren Verbesserung der Frequenzgrenze führen. Vorzugsweise verläuft die Variation der Bandbreite linear, während der Störstellengehalt konstant ist oder exponentiell verläuft.

Als miteinander zu kombinierende Halbleitersubstanzen kommen für die Erfindung alle die Halbleitermaterialien in Frage, die auch sonst für die Transistorherstellung geeignet sind, vorausgesetzt, daß die Symmetrie ihrer Kristallgitter dieselbe ist. Dies sind insbesondere die Halbleitersubstanzen der IV. Gruppe des periodischen Systems der Elemente, wie Germanium und Silizium, sowie die gemischten Halbleiter vom Typ $A_{III}B_V$. Und zwar kann man sowohl Halbleitermaterialien der IV. Gruppe untereinander, als auch einen oder mehrere Halbleitermaterialien der IV. Gruppe mit einem oder mehreren

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$A_{III}B_V$-Halbleitern, als auch mehrere $A_{III}B_V$-Halbleiter untereinander kombinieren.

Die Herstellung der erforderlichen dünnen Basisschichten mit inhomogener Zusammensetzung geschieht zweckmäßigerweise so, daß man eine geeignete Menge einer geeigneten flüssigen Mischung der Komponenten langsam von einer Seite her erstarren läßt. Dabei ändert sich die Zusammensetzung des erstarrten Kristalls stetig, beginnend mit der Halbleitersubstanz des höchsten Schmelzpunktes, die im ersten und im dritten Falle der obigen Kombinationsmöglichkeiten gleichzeitig die Halbleitersubstanz mit dem höchsten Bandabstand ist.

Vorzugsweise kann man diesen Schmelzprozeß so durchführen, daß man die niedrigschmelzende(n) Komponente(n) auf ein festes Kristallstück der höchstschmelzenden Komponente aufbringt und das Ganze so hoch erhitzt, daß erstere schmilzt bzw. schmelzen und eine geeignete Menge der letzteren auflöst bzw. auflösen, woraufhin man die Erstarrung wie oben beschrieben durchführt.

Der hochschmelzende Kristall und die niedrigschmelzende(n) Komponente(n) werden dabei zweckmäßigerweise in einander entgegengesetzter Richtung so vordotiert, so daß sich beim Erstarren sogleich der eine der beiden die Basiszone begrenzenden pn-Übergänge bildet.

Wir betrachten jetzt einmal näher den Fall eines nur zweikomponentigen Mischkristalls, wo die höchstschmelzende Komponente auch den höheren Bandabstand hat. Dann bildet der nach dem beschriebenen Verfahren zuerst entstehende pn-Übergang später den Emitter. Es ist dann zweckmäßig, zur Vordotierung des festen Kristalls einen Stoff mit sehr kleinem Verteilungskoeffizienten zu wählen, d. h. einen Stoff, der beim Erstarren bevorzugt in die flüssige Phase geht, während man die niedrigschmelzende Komponente zweckmäßigerweise mit einem Stoff mit einem möglichst großen Verteilungskoeffizienten, vorzugsweise einem Verteilungskoeffizienten > 1, vordotiert. Man erhält dann nämlich gleichzeitig beim Erstarren der Schmelze den gewünschten monotonen Abfall der (Netto-)Störstellenkonzentration. Wenn die Verteilungskoeffizienten der beiden Dotierungsstoffe sich hinreichend stark unterscheiden, überwiegt schließlich gegen Ende des Erstarrungsprozesses wieder die Störstellenart des Emitterkristalls, so daß auch der zweite die Basiszone begrenzende pn-Übergang, der Kollektorübergang, in demselben Vorgang entsteht. Durch Variation der Menge der zweiten Halbleiterkomponente und Variation der Fremdstoffgehalte lassen sich die physikalischen Parameter der so entstehenden Transistoren in weitem Bereich beeinflussen.

Im Falle einer Silizium-Germanium-Kombination eignen sich zur Dotierung des Emitterkristalls vorwiegend die Elemente der III. Gruppe des Periodensystems der Elemente wie Arsen oder Antimon, zur Dotierung des Germanium vorwiegend Bor und Aluminium. Dabei entstehen npn-Transistoren.

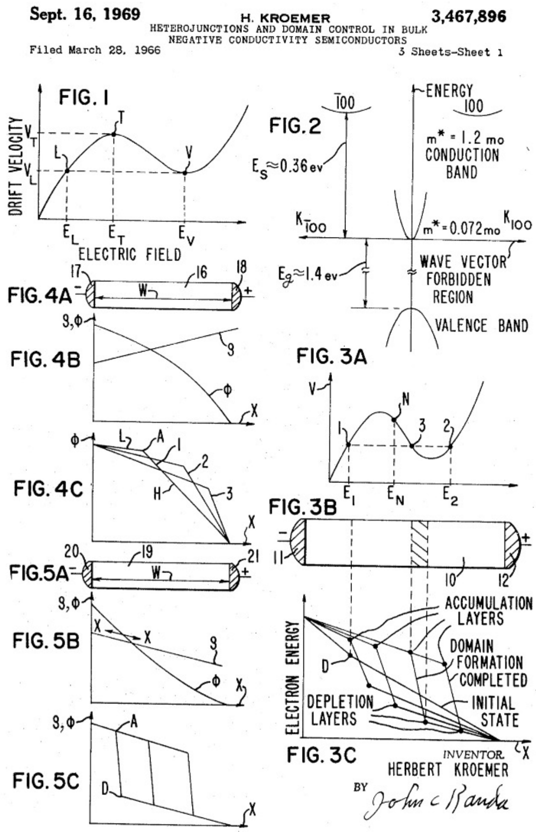
Ganz analoge Überlegungen gelten für mehrkomponentige Systeme für andere Halbleiterarten sowie für den Fall, daß die höherschmelzenden Komponenten den niedrigeren Bandabstand haben.

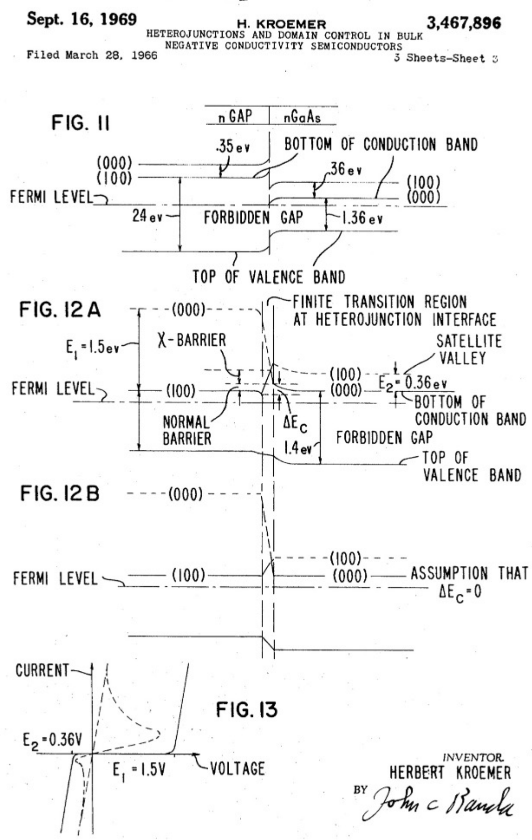
Patentansprüche:

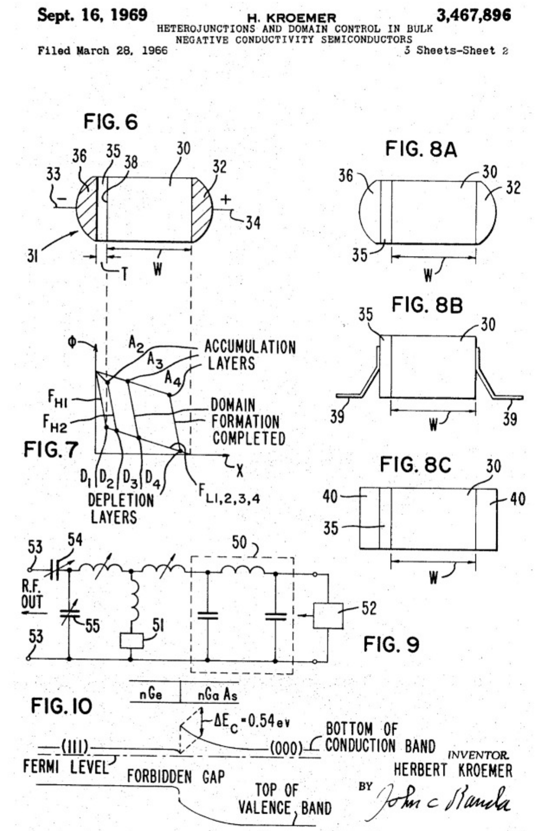
1. Drifttransistor, dadurch gekennzeichnet, daß ein elektrisches Feld in der

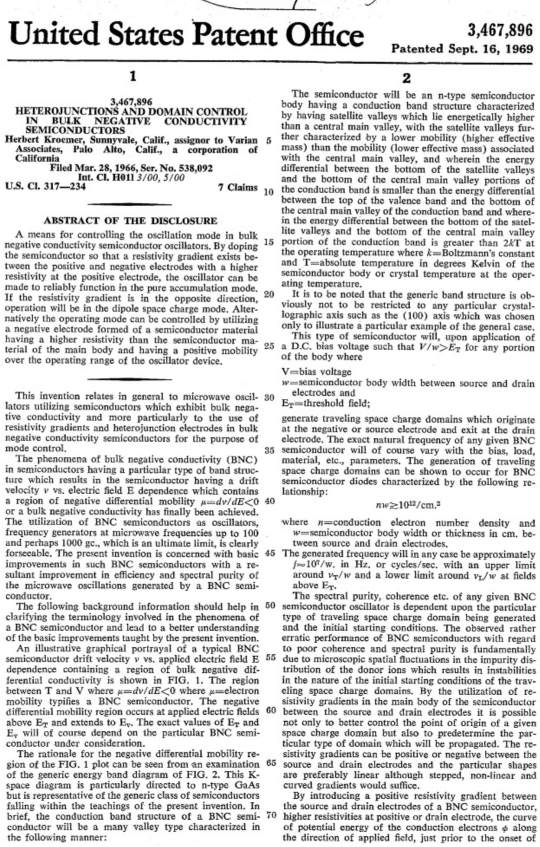
Figure 6.116: Herbert Kroemer invented the drift transistor in 1953 or earlier.

Herbert Kroemer invented III-V semiconductor heterostructures (1966 or earlier)








United States Patent Office

3,467,896
Patented Sept. 16, 1969

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3,467,896
HETEROJUNCTIONS AND DOMAIN CONTROL IN BULK NEGATIVE CONDUCTIVITY SEMICONDUCTORS
Herbert Kroemer, Sunnyvale, Calif., assignor to Varian Associates, Palo Alto, Calif., a corporation of California
Filed Mar. 28, 1966, Ser. No. 538,092
Int. Cl. H01l 3/00, 5/00
U.S. Cl. 317—234 7 Claims

ABSTRACT OF THE DISCLOSURE

A means for controlling the oscillation mode in bulk negative conductivity semiconductor oscillators. By doping the semiconductor so that a resistivity gradient exists between the positive and negative electrodes with a higher resistivity at the positive electrode, the oscillator can be made to reliably function in the pure accumulation mode. If the resistivity gradient is in the opposite direction, operation will be in the dipole space charge mode. Alternatively the operating mode can be controlled by utilizing a negative electrode formed of a semiconductor material having a higher resistivity than the semiconductor material of the main body and having a positive mobility over the operating range of the oscillator device.

This invention relates in general to microwave oscillators utilizing semiconductors which exhibit bulk negative conductivity and more particularly to the use of resistivity gradients and heterojunction electrodes in bulk negative conductivity semiconductors for the purpose of mode control.

The phenomena of bulk negative conductivity (BNC) in semiconductors having a particular type of band structure which results in the semiconductor having a drift velocity v vs. electric field E dependence which contains a region of negative differential mobility $\mu = dv/dE < 0$ or a bulk negative conductivity has finally been achieved. The utilization of BNC semiconductors as oscillators, frequency generators at microwave frequencies up to 100 and perhaps 1000 gc., which is an ultimate limit, is clearly forseeable. The present invention is concerned with basic improvements in such BNC semiconductors with a resultant improvement in efficiency and spectral purity of the microwave oscillations generated by a BNC semiconductor.

The following background information should help in clarifying the terminology involved in the phenomena of a BNC semiconductor and lead to a better understanding of the basic improvements taught by the present invention.

An illustrative graphical portrayal of a typical BNC semiconductor drift velocity v vs. applied electric field E dependence containing a region of bulk negative differential conductivity is shown in FIG. 1. The region between T and V where $\mu = dv/dE < 0$ where μ=electron mobility typifies a BNC semiconductor. The negative differential mobility region occurs at applied electric fields above E_T and extends to E_v. The exact values of E_T and E_v will of course depend on the particular BNC semiconductor under consideration.

The rationale for the negative differential mobility region of the FIG. 1 plot can be seen from an examination of the generic energy band diagram of FIG. 2. This K-space diagram is particularly directed to n-type GaAs but is representative of the generic class of semiconductors falling within the teachings of the present invention. In brief, the conduction band structure of a BNC semiconductor will be a many valley type characterized in the following manner:

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The semiconductor will be an n-type semiconductor body having a conduction band structure characterized by having satellite valleys which lie energetically higher than a central main valley, with the satellite valleys further characterized by a lower mobility (higher effective mass) than the mobility (lower effective mass) associated with the central main valley, and wherein the energy differential between the bottom of the satellite valleys and the bottom of the central main valley portions of the conduction band is smaller than the energy differential between the top of the valence band and the bottom of the central main valley of the conduction band and wherein the energy differential between the bottom of the satellite valleys and the bottom of the central main valley portion of the conduction band is greater than $2kT$ at the operating temperature where k=Boltzmann's constant and T=absolute temperature in degrees Kelvin of the semiconductor body or crystal temperature at the operating temperature.

It is to be noted that the generic band structure is obviously not to be restricted to any particular crystallographic axis such as the (100) axis which was chosen only to illustrate a particular example of the general case.

This type of semiconductor will, upon application of a D.C. bias voltage such that $V/w > E_T$ for any portion of the body where

V=bias voltage
w=semiconductor body width between source and drain electrodes and
E_T=threshold field;

generate traveling space charge domains which originate at the negative or source electrode and exit at the drain electrode. The exact natural frequency of any given BNC semiconductor will of course vary with the bias, load, material, etc., parameters. The generation of traveling space charge domains can be shown to occur for BNC semiconductor diodes characterized by the following relationship:

$$nw \gtrsim 10^{12}/\text{cm.}^2$$

where n=conduction electron number density and w=semiconductor body width or thickness in cm. between source and drain electrodes.

The generated frequency will in any case be approximately $f \approx 10^7/w$. in Hz. or cycles/sec. with an upper limit around v_T/w and a lower limit around v_L/w at fields above E_T.

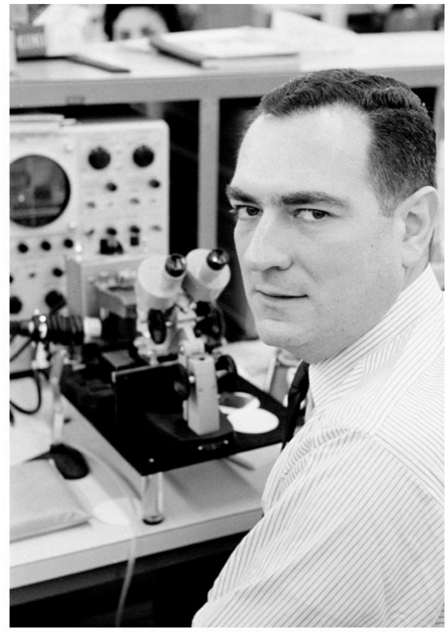
The spectral purity, coherence etc. of any given BNC semiconductor oscillator is dependent upon the particular type of traveling space charge domain being generated and the initial starting conditions. The observed rather erratic performance of BNC semiconductors with regard to poor coherence and spectral purity is fundamentally due to microscopic spatial fluctuations in the impurity distribution of the donor ions which results in instabilities in the nature of the initial starting conditions of the traveling space charge domains. By the utilization of resistivity gradients in the main body of the semiconductor between the source and drain electrodes it is possible not only to better control the point of origin of a given space charge domain but also to predetermine the particular type of domain which will be propagated. The resistivity gradients can be positive or negative between the source and drain electrodes and the particular shapes are preferably linear although stepped, non-linear and curved gradients would suffice.

By introducing a positive resistivity gradient between the source and drain electrodes of a BNC semiconductor, higher resistivities at positive or drain electrode, the curve of potential energy of the conduction electrons ϕ along the direction of applied field, just prior to the onset of

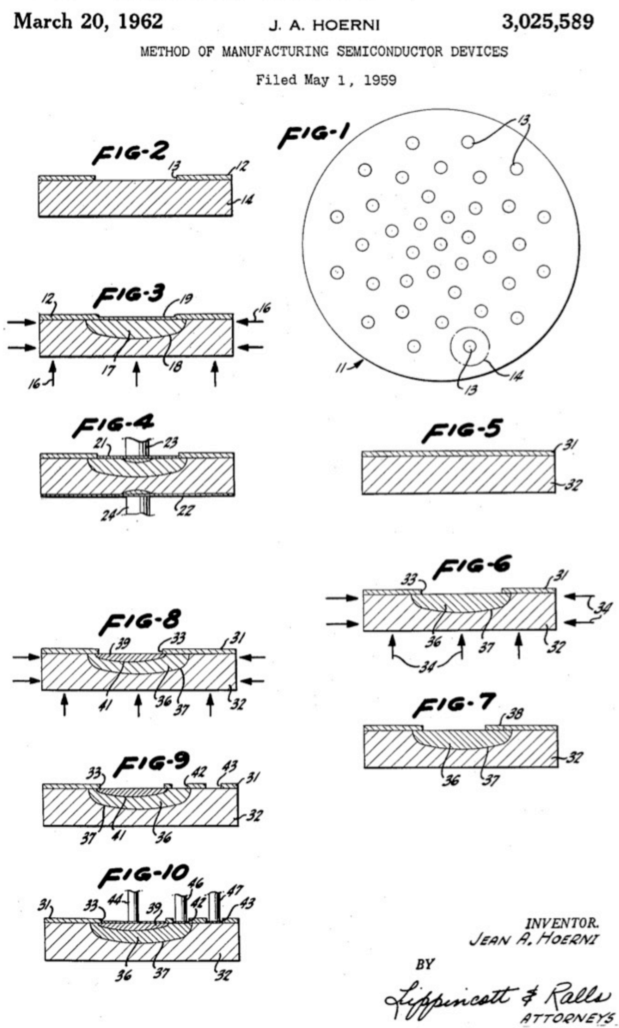
Figure 6.117: Herbert Kroemer invented III-V semiconductor heterostructures in 1966 or earlier.

Jean Hoerni (1924–1997)

Eugene Kleiner (1923–2003)



Silicon transistor manufacturing



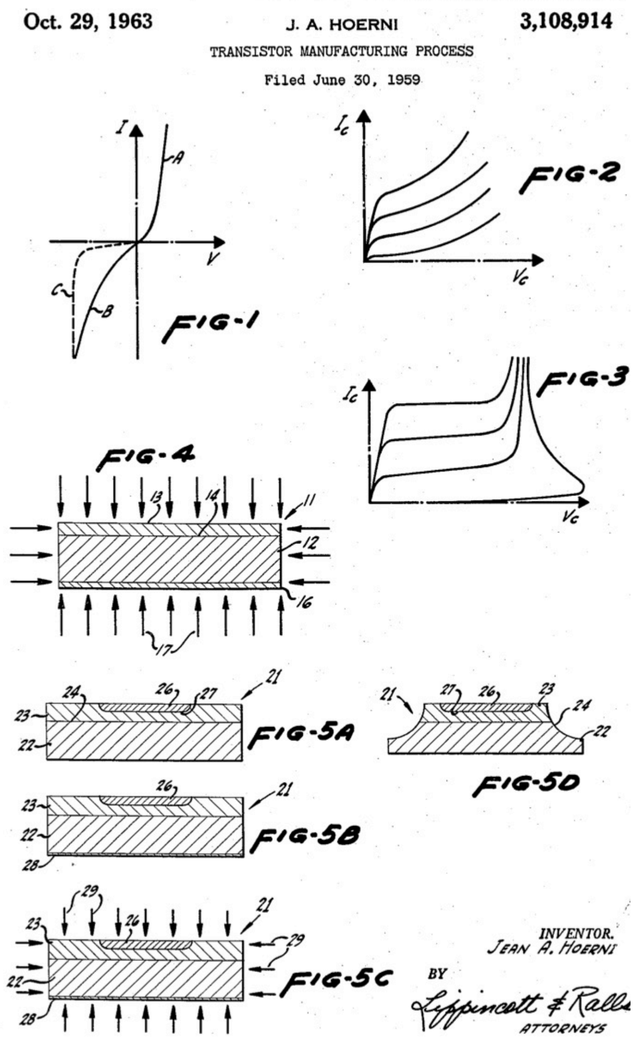
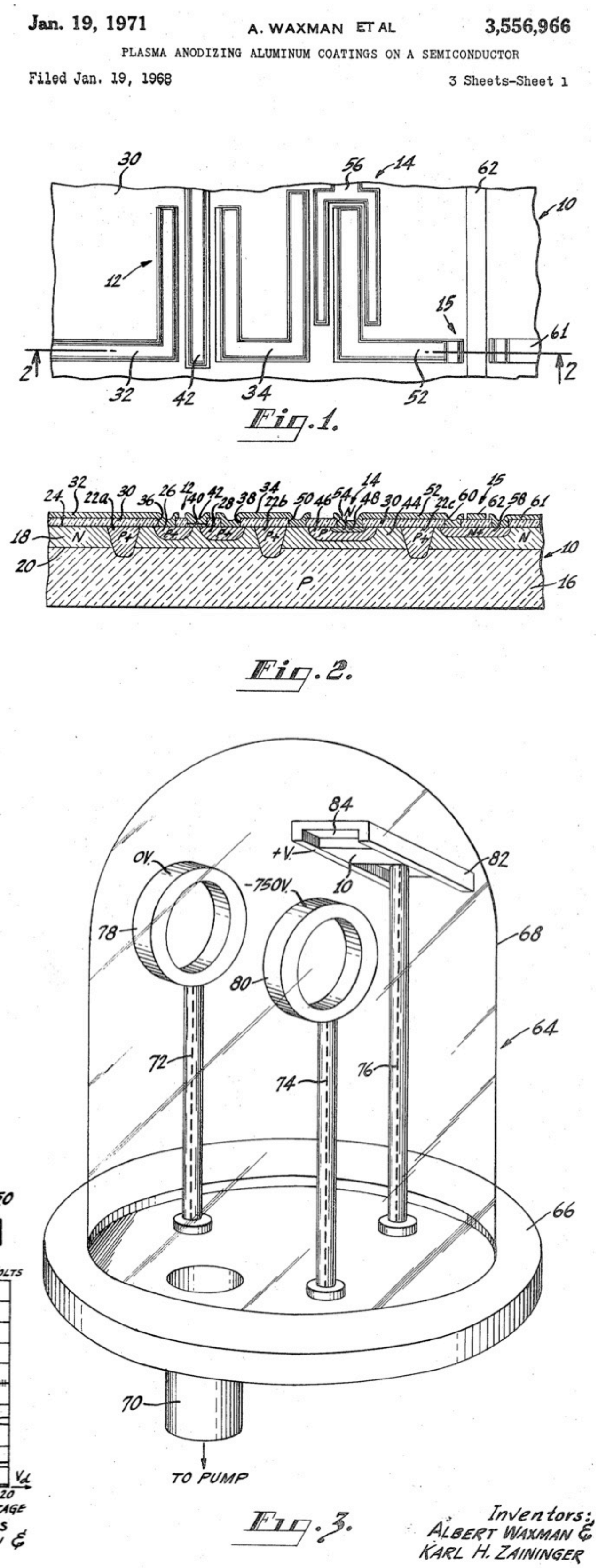


Figure 6.118: Jean Hoerni and Eugene Kleiner developed methods of manufacturing silicon transistors.

Karl Heinz Zaininger (1929–)
Field effect transistor manufacturing



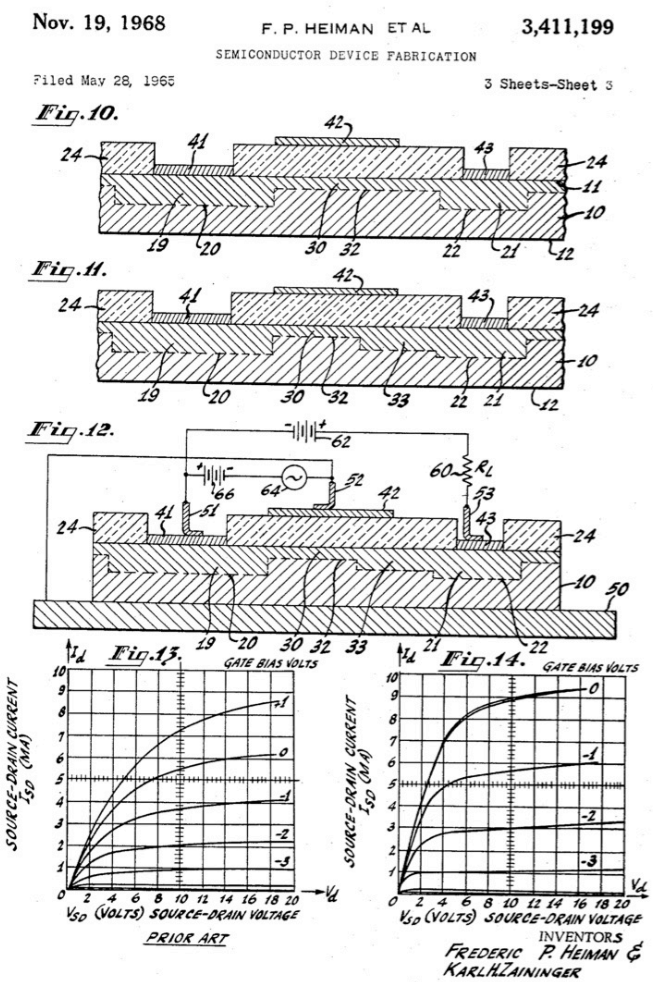


Figure 6.119: Karl Heinz Zaininger developed modern methods for fabricating field effect transistors.

Helmut Gröttrup (1916–1981)

Jürgen Dethloff (1924–2002)

Invented smart card, or chip card (1966)

Nr. **512 793** **PATENTSCHRIFT** Nr. **512 793**

Internationale Klassifikation:	G 07 c 1/00 G 07 c 11/00 G 07 f 5/26 G 06 k 7/00
Gesuchsnummer:	9939/70
Anmeldungsdatum:	30. Juni 1970, 18 Uhr
Priorität:	Oesterreich, 30. Juni 1969 (A 6199/69)
Patent erteilt:	15. September 1971
Patentschrift veröffentlicht:	29. Oktober 1971

SCHWEIZERISCHE EIDGENOSSENSCHAFT

EIDGENÖSSISCHES AMT FÜR GEISTIGES EIGENTUM

C

HAUPTPATENT

Jürgen Dethloff, Hamburg, und Helmut Gröttrup, München
(Bundesrepublik Deutschland)

Identifizierungsanordnung mit einer Anzahl frei beweglicher Identifikanden und einem Identifikator

Jürgen Dethloff, Hamburg, und Helmut Gröttrup, München (Bundesrepublik Deutschland), sind als Erfinder genannt worden

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Die Erfindung betrifft eine Identifizierungsanordnung mit einer Anzahl frei beweglicher Träger von maschinell auswertbaren, diesen Träger kennzeichnenden Informationen, im folgenden Identifikand genannt, und einer Einrichtung, im folgenden Identifikator genannt, zur Auswertung der im Identifikanden gespeicherten Informationen zum Zwecke der automatischen Verarbeitung von mit dem Identifikanden ausgelösten Benutzungshandlungen, wobei der Identifikand zwischen seinen Eingängen und Ausgängen einen Zuordner enthält, dessen Verknüpfungen den Identifikanden kennzeichnen.

Die genannte Aufgabe liegt z. B. bei der Personenidentifizierung vor, um auf Grund dieser Identifikation bestimmte Vorgänge automatisch auszulösen, was von der Werkeingangskontrolle in Betrieben bis zum bargeldlosen Kauf über Automaten reichen kann. Die Identifizierung von Sachen entsteht als Aufgabe z. B. bei dem Durchlauf von Fertigungslosen durch Werkstätten oder bei der Ortsbestimmung von Fahrzeugen.

Gemäss einem früheren Vorschlag werden die Informationen der verschiedenen Identifikanden durch die verschiedenen Verknüpfungen der in den Identifikanden enthaltenen Zuordnerschaltung dargestellt. Der Identifikator weist eine Anzahl von Sendepunkten und Empfangspunkten auf, zwischen denen der Identifikand entsprechend seinen Verknüpfungen Verbindungen herstellt. Das Grundprinzip des Identifikators besteht darin, dass die Sendepunkte mit definierten Impulsströmen über die im Identifikanden enthaltene Verknüpfung auf die Empfangspunkte des Identifikators einwirken und in diesem auf diese Weise den Code des Identifikanden einspeichern. Der Identifikand und der Identifikator

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besitzen jeweils die gleiche Anzahl, z. B. zehn, räumlich diskreter Empfangs- und Sendestellen.

Mit dieser bekannten Anordnung ist eine Paralleleingabe der abfragenden Impulse aus dem Identifikator und eine Parallelausgabe der Identifizierungsimpulse aus dem Identifikanden in den Identifikator möglich. Das Zuordnungsprinzip ist aber nicht an den Parallelbetrieb und an die räumlich diskreten Sende- und Empfangsstellen gebunden.

Die vorliegende Erfindung besteht nun darin, dass im Identifikator eine Sendeeinrichtung vorgesehen ist, mit deren Hilfe dem Identifikanden nacheinander eine der Anzahl der Zuordnungsstellen des Identifikanden entsprechende Anzahl von Informationen angeboten wird, dass im Identifikanden eine Wähleinrichtung vorhanden ist, die die eintreffenden Informationen der Reihe nach den Eingängen des im Identifikanden enthaltenen Zuordners zuführt, und dass im Identifikanden eine Sendeeinrichtung vorgesehen ist, deren Modulation durch die Ausgänge des Zuordners bestimmt wird und mittels welcher Sendeeinrichtung, die durch den Zuordner bestimmte Modulation direkt oder indirekt an den Identifikator zur Verarbeitung übertragen wird.

Zur Verteilung der Informationen kann beispielsweise im Identifikator ein Taktgeber vorgesehen sein, dessen Impulse die Eingänge des im Identifikanden befindlichen Zuordners nacheinander markieren, wobei jedem Ausgang des Zuordners eine Impulsgruppe mit einer bestimmten Impulszahl zugeordnet ist, so dass die nacheinander auftretenden Impulsgruppen den Code des betreffenden Identifikanden darstellen. Die Impulsgruppen können durch einen Impulsgruppengenerator gewonnen werden, der entsprechend dem markierten

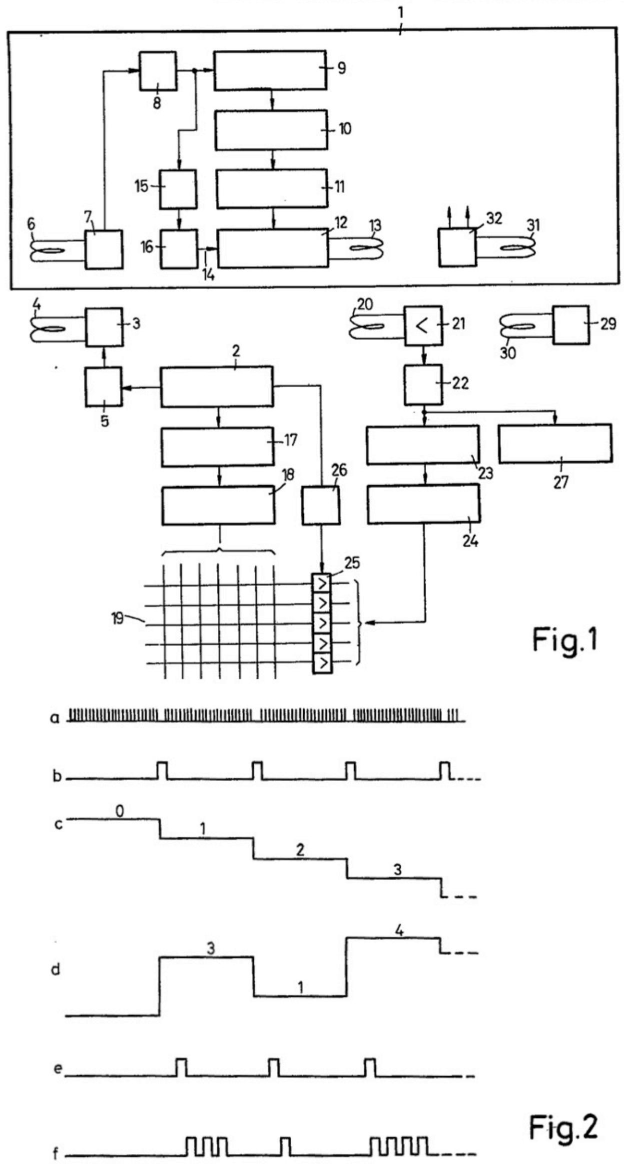

Figure 6.120: Helmut Gröttrup and Jürgen Dethloff invented the smart card, or chip card, in 1966.

6.5.8 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. They also developed improved photoelectric cells. See pp. 1115 and 2901.

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. 1116 and 2902–2906.

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 Fig. 6.123 and pp. 1106, 2769–2771, and 2907–2922.

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. See p. 1118.

Walter Heywang (German, 1923–2010) filed detailed patent applications on laser diodes in 1958 (pp. 1119 and 2924–2928)

Herbert Kroemer (German, 1928–) invented the drift transistor in 1953, the double-heterostructure laser diode in 1963, and III-V semiconductor heterostructures in 1966. (See pp. 1120 and 2929–2934.) He won the Nobel Prize in Physics in 2000 for his innovations in microelectronics. Professor Tord Claeson of the Royal Swedish Academy of Sciences described Kroemer's contributions [https://www.nobelprize.org/prizes/physics/2000/ceremony-speech/]:

> Early transistors were relatively slow. Semiconductor heterojunctions were proposed as a way of increasing amplification and achieving higher frequencies and power. Such a heterostructure consists of two semiconductors whose atomic structures fit one another well, but which have different electronic properties. A carefully worked out proposal was published in 1957 by Herbert Kroemer. Today, high-speed transistors are found in mobile (cellular) phones and in their base stations, in satellite dishes and links. There they are part of devices that amplify weak signals from outer space or from a faraway mobile telephone without drowning in the noise of the receiver itself.
>
> Semiconductor heterostructures have been at least equally important to the development of photonics—lasers, light emitting diodes, modulators and solar panels, to mention a few examples. The semiconductor laser is based upon the recombination of electrons

> and holes, emitting particles of light, photons. If the density of these photons becomes sufficiently high, they may begin to move in rhythm with each other and form a phase-coherent state, that is, laser light. The first semiconductor lasers had low efficiency and could only shine in short pulses.
>
> Herbert Kroemer and Zhores Alferov suggested in 1963 that the concentration of electrons, holes and photons would become much higher if they were confined to a thin semiconductor layer between two others—a double heterojunction. [...]
>
> Lasers and light emitting diodes (LEDs) have been further developed in many stages. Without the heterostructure laser, today we would not have had optical broadband links, CD players, laser printers, bar code readers, laser pointers and numerous scientific instruments. LEDs are used in displays of all kind, including traffic signals. Perhaps they will entirely replace light bulbs. In recent years, it has been possible to make LEDs and lasers that cover the full visible wavelength range, including blue light.
>
> I have emphasized the technical consequences of these discoveries, since these are easier to explain than the spectacular scientific breakthroughs that they have also led to. Challenging problems and matching resources have led to large-scale basic research. The advanced materials and tools of microelectronics are being used for studies in nanoscience and of quantum effects. Scientific experiments and computations are, of course, highly computerized.
>
> Semiconductor heterostructures can be regarded as laboratories of two-dimensional electron gases. The 1985 and 1998 Nobel Prizes in physics for quantum Hall effects were based on such confined geometries. They can be reduced further to form one-dimensional quantum channels and zero-dimensional quantum dots for future studies.

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)

Improved photoelectric cells and prototype light emitting diodes (LEDs) (1919–1923)

Zeitschrift für Physik 18:1:199–206 (1923)

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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.

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

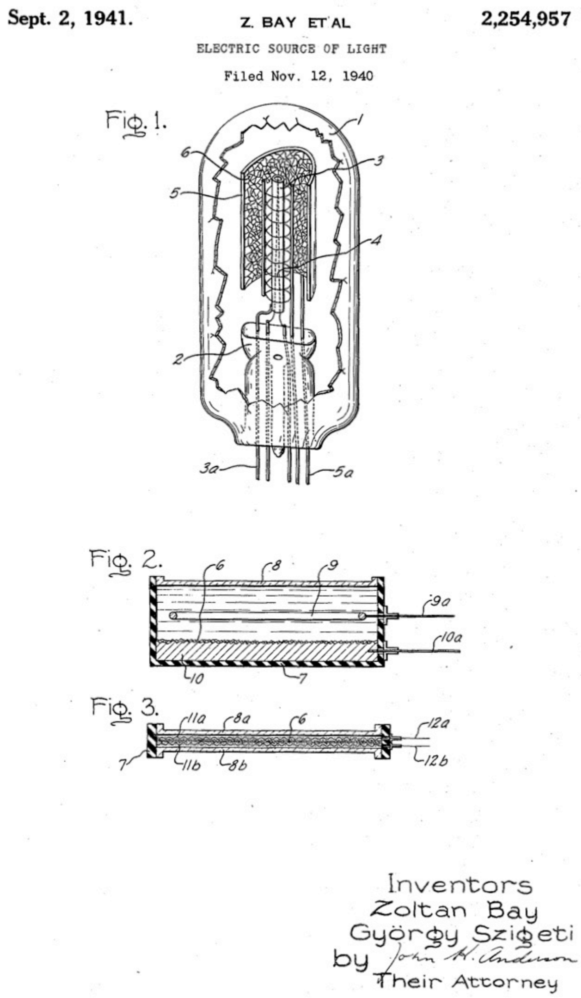
Robert Pohl (1884–1976)

Figure 6.121: Bernhard Gudden and Robert Pohl developed improved photoelectric cells and also electroluminescent semiconductor devices, the direct forerunners of light emitting diodes (LEDs), during the period 1919–1923 [*Zeitschrift für Physik* 18:1:199–206 (1923)].

Zoltan Bay
(1900–1992)

György
Szigeti
(1905–1978)

Filed patent applications on an improved light emitting diode (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.

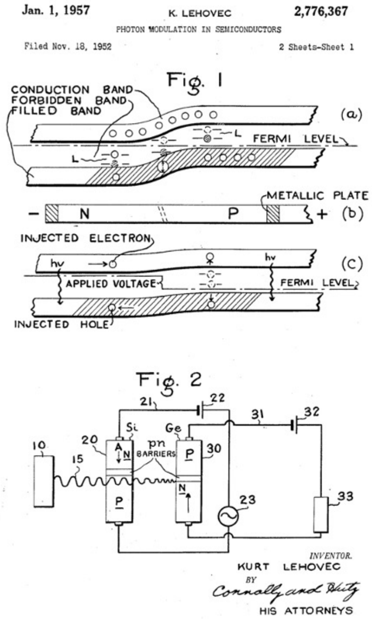
Faint luminous phenomena have already been observed on the carborundum crystals of crystal detectors at the point of contact between the needle and the crystal, where minute luminous points have appeared. This phenomenon was interpreted by its first observer as representing a cold electron discharge, 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.

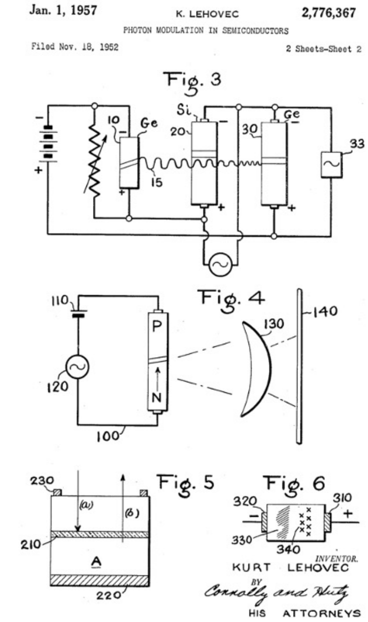
It is also known that the layer formed in certain cases on the surface of electrically semi-conductive bodies, as for instance, on the effective surfaces of dry rectifiers, crystal detectors or condensers of the electrolyte type, will emit

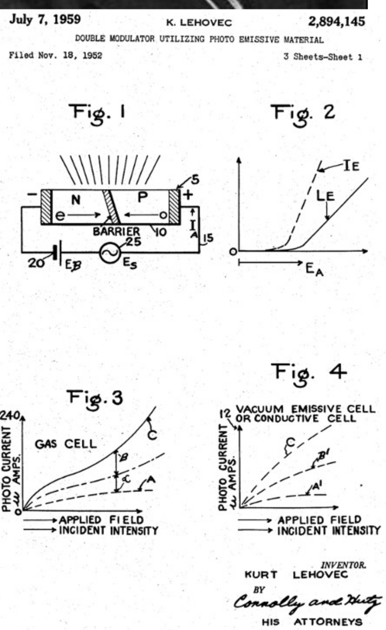
Figure 6.122: Zoltan Bay and György Szigeti filed patent applications on light emitting diodes (LEDs) in 1939.

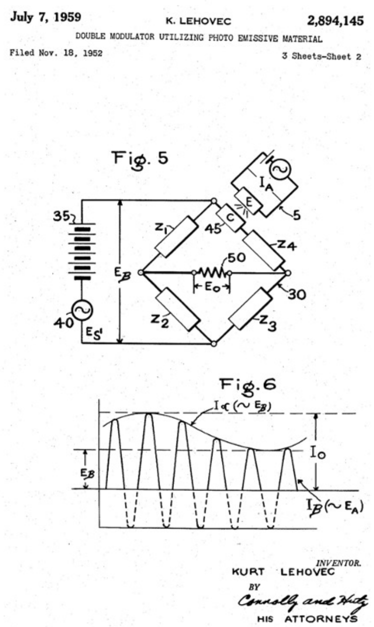
Improved LEDs

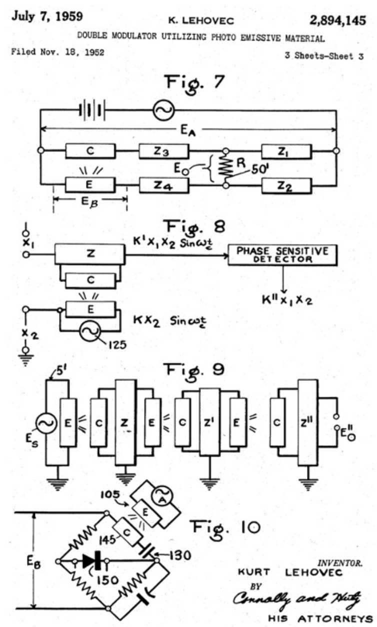
Kurt Lehovec (1918–2012)
Was his postwar work in U.S. based on wartime work in Bernhard Gudden's lab?











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

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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,

United States Patent Office **2,894,145** Patented July 7, 1959

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2,894,145

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

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combination. 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

Figure 6.123: Kurt Lehovec worked closely with Bernhard Gudden (p. 1115) on advanced semiconductor devices throughout WWII came to the U.S. after the war, and filed patents on improved light emitting diodes (LEDs). How much of Lehovec's postwar work was based on his wartime work with Gudden?

John von Neuman (1903–1957) made a detailed proposal for semiconductor lasers (or 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

REFERENCES

I.: *International Critical Tables*. New York, London: NRC-McGraw Hill, 1929.

H.: W. Heitler, The Quantum Theory of Radiation. Oxford, England: Oxford Univ. Press, 1944, 2nd ed.

Sh.: W. Shockley, Electrons and Holes in Semiconductors. New York: Van Nostrand, 1950.

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 $\vec{r} \to \vec{r} + d\vec{j}$, 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 $\vec{r} \to \vec{r} + \vec{d}_j$ merely multiplies ψ_a by a constant factor of absolute value 1, $\Theta(\vec{j})$:

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

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 6.124: 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)].

Walter Heywang (1923–2010) filed patent applications on semiconductor lasers, or laser diodes (1958)

United States Patent Office

3,121,203
Patented Feb. 11, 1964

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3,121,203
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

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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.

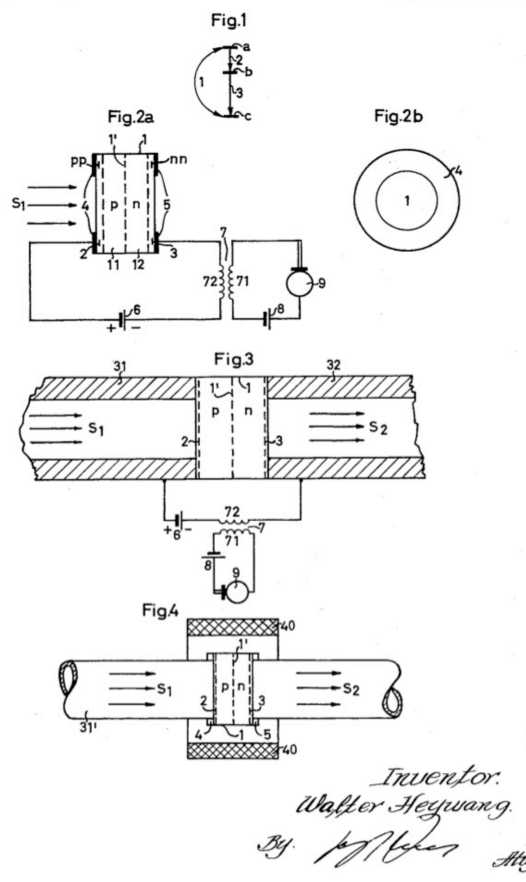
The invention avoids these disadvantages in most surprisingly simple manner by providing an arrangement for amplifying very high frequency radiation according to the Maser principle, comprising (*a*) an electron-conducting, particularly a mono-crystalline semi-conductor body having two mutually different 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, bismuthtellurid (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

Feb. 11, 1964 W. HEYWANG **3,121,203**
SEMICONDUCTOR MASER WITH MODULATING MEANS
Filed April 22, 1959 2 Sheets-Sheet 1



Feb. 11, 1964 W. HEYWANG **3,121,203**
SEMICONDUCTOR MASER WITH MODULATING MEANS
Filed April 22, 1959 2 Sheets-Sheet 2

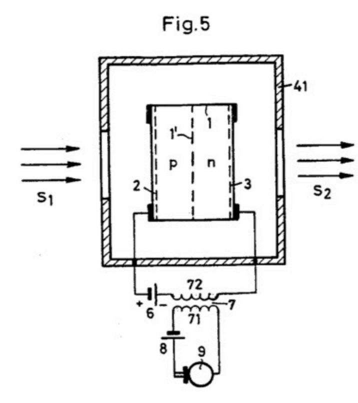


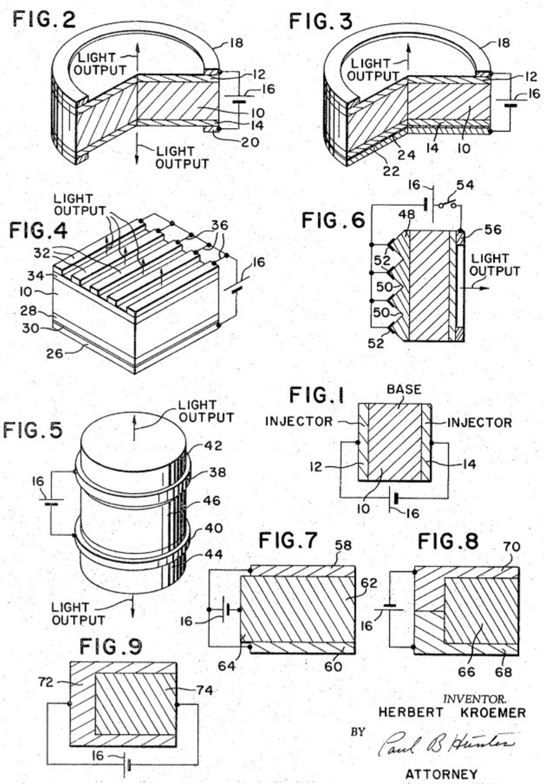
Figure 6.125: Walter Heywang filed detailed patent applications on laser diodes in 1958.

Herbert Kroemer (1928–) invented double-heterostructure laser diodes (1963 or earlier)

March 14, 1967 H. KROEMER **3,309,553**

SOLID STATE RADIATION EMITTERS

Filed Aug. 16, 1963



United States Patent Office

3,309,553
Patented Mar. 14, 1967

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3,309,553
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 electrodes 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.

3,309,553

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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

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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 6.126: Herbert Kroemer invented the double-heterostructure laser diode in 1963 or earlier.

6.5.9 Superconductivity

As illustrated in Figs. 6.127–6.132, creators from the German-speaking world also dominated research on superconductivity, the elimination of electrical resistance (and thus the elimination of power losses) when conductive materials are sufficiently cold.

Heike Kamerlingh Onnes (Dutch, educated in Germany, 1853–1926) produced the first liquid helium in 1908. By immersing metals in the liquid helium and measuring their electrical properties, he discovered superconductivity in 1911 (Fig. 6.127). He won the Nobel Prize in Physics in 1913 for all of his research on cryogenics—see p. 929 for more information.

Max von Laue (German, 1879–1960), Fritz Walther Meissner (German, 1882–1974), and Robert Ochsenfeld (German, 1901–1993) further studied the properties of superconductors (Fig. 6.128). Max von Laue won the Nobel Prize in Physics in 1914 for some of his other research (p. 674). In 1933, Meissner and Ochsenfeld discovered the now widely known Meissner (or Meissner-Ochsenfeld) effect, the levitation of a magnet above a superconductor; magnetic fields cannot penetrate a superconductor, so the compressed field between a magnet and a superconductor acts as a cushion.

From the late 1920s onward, Kurt Mendelssohn (German, 1906–1980) also extensively studied superconductivity, including the effects of lattice imperfections on superconductivity in various metal alloys. He studied superfluidity, the unusual behavior of fluids at cryogenic temperatures, as well, and he found direct analogies between the electrical behavior of superconductors and the mechanical behavior of superfluids.

In 1935, the brothers Fritz London (German, 1900–1954) and Heinz London (German, 1907–1970) developed the London equations, which provided a theoretical derivation and explanation for the Meissner effect and some other electromagnetic behaviors of superconductors.

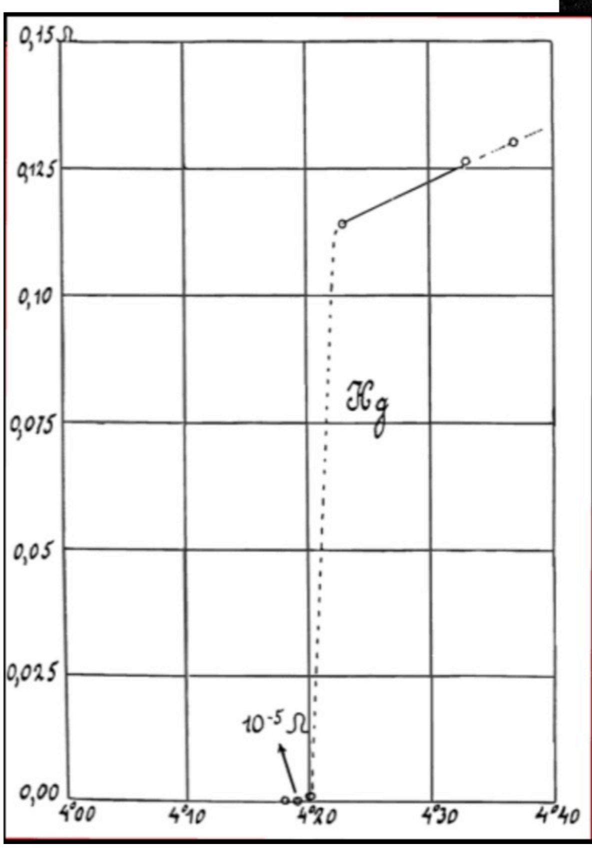
Many of those experts on superconductivity fled Germany before World War II and spread their knowledge to other countries, but U.S. and U.K. reports also described impressive work on superconductivity that was carried out by other scientists in Germany and Austria during the war. For example, BIOS 1751, *German Research on Semi-Conductors, Metal Rectifiers, Detectors and Photocells*, gave some insight into one of Rudolf Hilsch's later projects [BIOS 1751]:

> Super-Conductivity[...] Hilsch [...] has investigated the critical temperature ("Sprungpunkt") of various pure metals, (i.e. that temperature at which super-conduction sets in), also the influence of a magnetic field (which has the effect of lowering the critical temperature) and the critical current ("Grenzstrom") which sets up a magnetic field of such magnitude as just to balance the external field. He also studied the very pronounced effects which some metals have on the critical temperature even if added in very small amounts only.

According to official histories, in 1956 the American Leon Cooper first proposed a detailed explanation of superconductivity, focusing on what came to be known as "Cooper pairs" of electrons that work together to avoid electrical resistance. Cooper won the Nobel Prize in Physics for that explanation. The document on pp. 1125–1127 proves that Josef Schintlmeister (Austrian, 1908–1971) and his coworkers had a detailed understanding of this physics no later than 1945, and were forced to give written reports on that to the United States. Scholars should investigate in much more detail the superconductivity research that Schintlmeister and his coworkers carried out, and how information on their discoveries may have influenced later researchers such as Cooper.

Heike Kamerlingh Onnes (1853–1926)

Discovered superconductivity (1911)



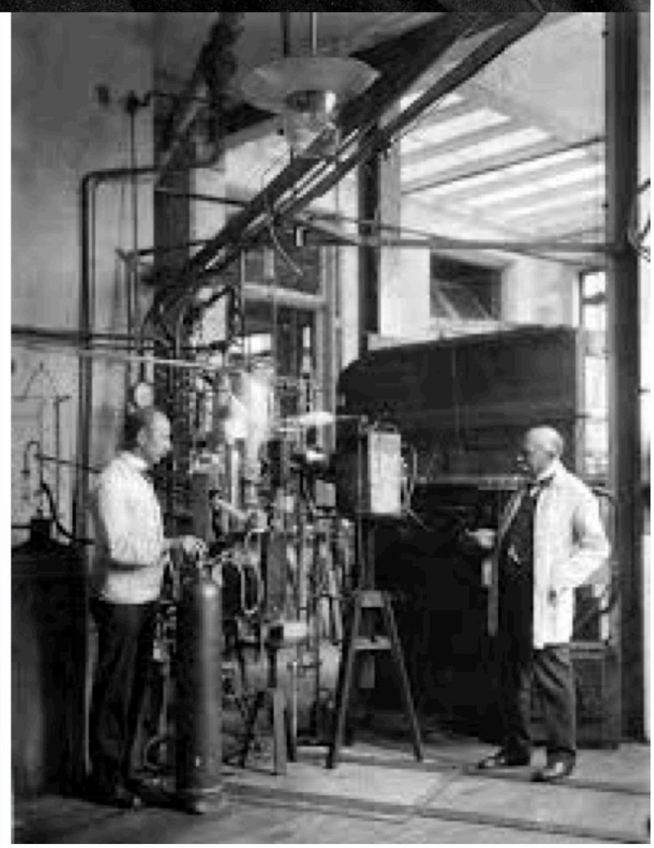


Figure 6.127: Heike Kamerlingh Onnes discovered superconductivity in 1911.

Figure 6.128: Max von Laue, Fritz Walther Meissner, and Robert Ochsenfeld further studied the properties of superconductors, including the “Meissner effect” or magnetic levitation.

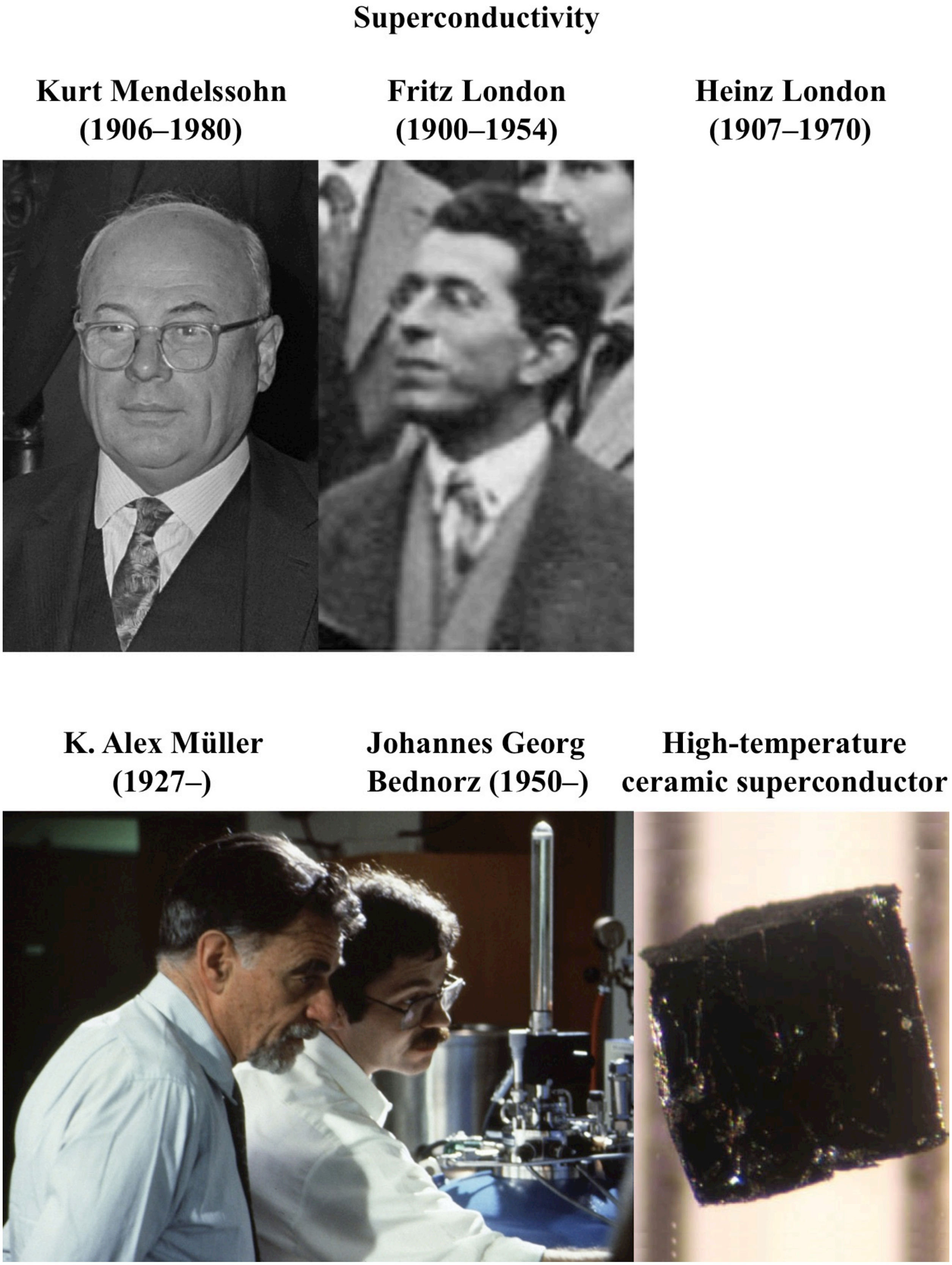
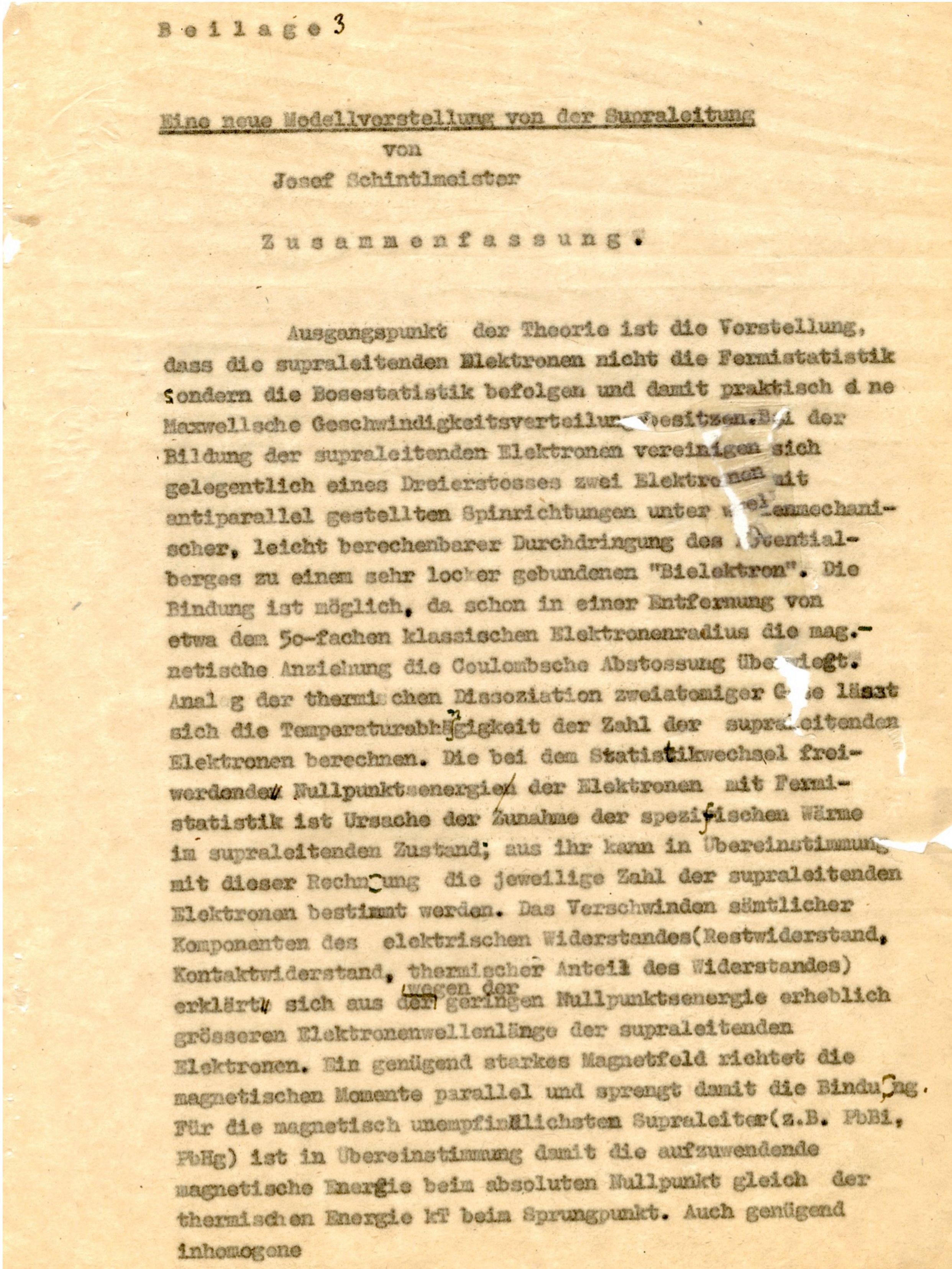


Figure 6.129: Other important pioneers of superconductivity included Kurt Mendelssohn, as well as the brothers Fritz London and Heinz London. K. Alex Müller and his student Johannes Georg Bednorz developed the first high-temperature ceramic superconductors.



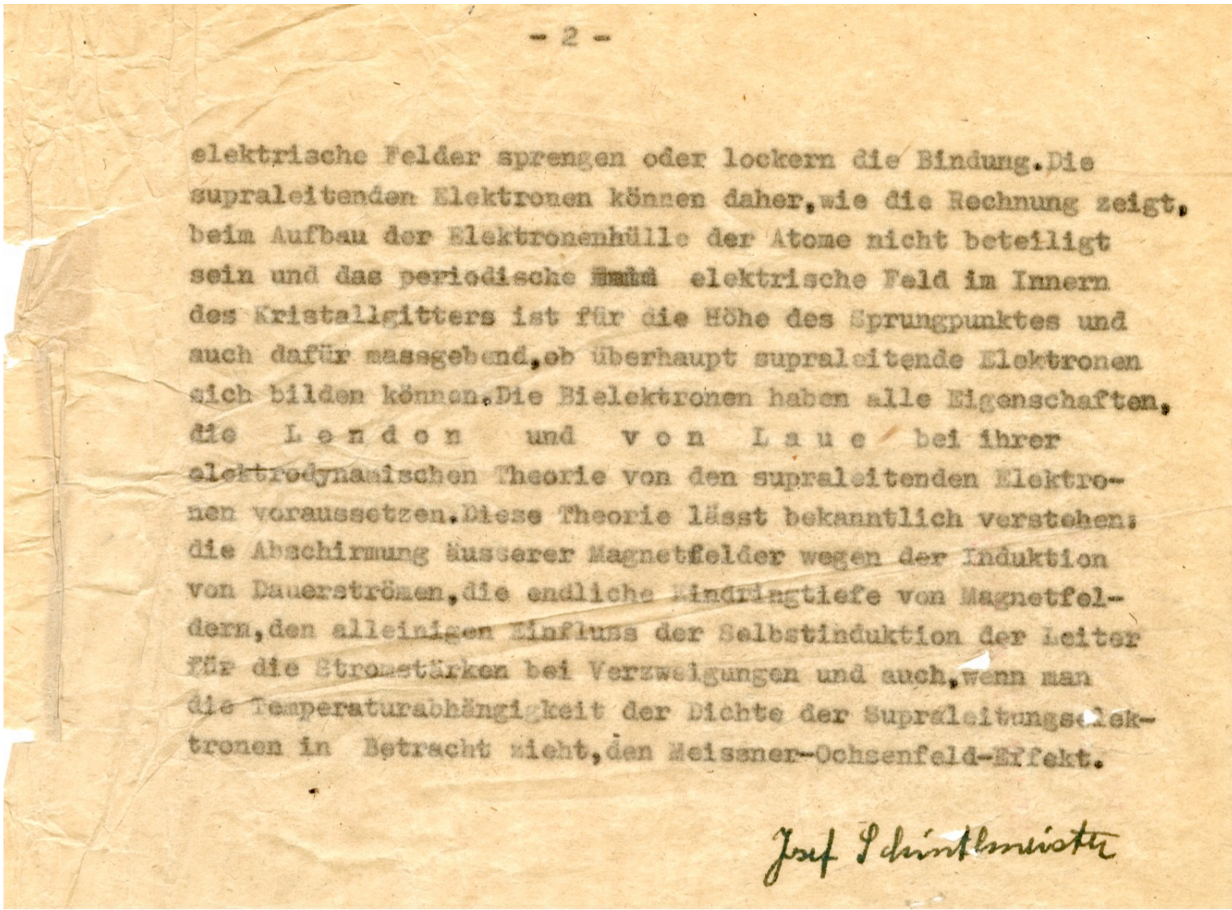
Beilage 3

Eine neue Modellvorstellung von der Supraleitung
von
Josef Schintlmeister

Zusammenfassung.

Ausgangspunkt der Theorie ist die Vorstellung, dass die supraleitenden Elektronen nicht die Fermistatistik sondern die Bosestatistik befolgen und damit praktisch die Maxwellsche Geschwindigkeitsverteilung besitzen. Bei der Bildung der supraleitenden Elektronen vereinigen sich gelegentlich eines Dreierstosses zwei Elektronen mit antiparallel gestellten Spinrichtungen unter wellenmechanischer, leicht berechenbarer Durchdringung des Potentialberges zu einem sehr locker gebundenen "Bielektron". Die Bindung ist möglich, da schon in einer Entfernung von etwa dem 5o-fachen klassischen Elektronenradius die magnetische Anziehung die Coulombsche Abstossung überwiegt. Analog der thermischen Dissoziation zweiatomiger Gase lässt sich die Temperaturabhängigkeit der Zahl der supraleitenden Elektronen berechnen. Die bei dem Statistikwechsel freiwerdende Nullpunktsenergie der Elektronen mit Fermistatistik ist Ursache der Zunahme der spezifischen Wärme im supraleitenden Zustand; aus ihr kann in Übereinstimmung mit dieser Rechnung die jeweilige Zahl der supraleitenden Elektronen bestimmt werden. Das Verschwinden sämtlicher Komponenten des elektrischen Widerstandes (Restwiderstand, Kontaktwiderstand, thermischer Anteil des Widerstandes) erklärt sich aus wegen der geringen Nullpunktsenergie erheblich grösseren Elektronenwellenlänge der supraleitenden Elektronen. Ein genügend starkes Magnetfeld richtet die magnetischen Momente parallel und sprengt damit die Bindung. Für die magnetisch unempfindlichsten Supraleiter (z.B. PbBi, PbHg) ist in Übereinstimmung damit die aufzuwendende magnetische Energie beim absoluten Nullpunkt gleich der thermischen Energie kT beim Sprungpunkt. Auch genügend inhomogene

Figure 6.130: Josef Schintlmeister developed a correct theory of superconductivity, later known as Cooper pairs of electrons, no later than 1945 [G-345, Deutsches Museum FA 002/0712; English translation in FIAT 63].



- 2 -

elektrische Felder sprengen oder lockern die Bindung.Die supraleitenden Elektronen können daher,wie die Rechnung zeigt, beim Aufbau der Elektronenhülle der Atome nicht beteiligt sein und das periodische elektrische Feld im Innern des Kristallgitters ist für die Höhe des Sprungpunktes und auch dafür massgebend,ob überhaupt supraleitende Elektronen sich bilden können.Die Bielektronen haben alle Eigenschaften, die L o n d o n und v o n L a u e bei ihrer elektrodynamischen Theorie von den supraleitenden Elektronen voraussetzen.Diese Theorie lässt bekanntlich verstehen: die Abschirmung äusserer Magnetfelder wegen der Induktion von Dauerströmen,die endliche Eindringtiefe von Magnetfeldern,den alleinigen Einfluss der Selbstinduktion der Leiter für die Stromstärken bei Verzweigungen und auch,wenn man die Temperaturabhängigkeit der Dichte der Supraleitungselektronen in Betracht zieht,den Meissner-Ochsenfeld-Effekt.

Josef Schintlmeister

Josef Schintlmeister
(1908–1971)

Detailed theory of superconductivity, much later called "Cooper" electron pairs

Figure 6.131: Josef Schintlmeister developed a correct theory of superconductivity, later known as Cooper pairs of electrons, no later than 1945 [G-345, Deutsches Museum FA 002/0712; English translation in FIAT 63].

T. M. Odarenko. FIAT 63. *Activities of the Second Institute of Physics of the University of Vienna.* p. 30 [the original German version of this report is G-345, pp. 1125–1126]:

Supplement 3.

Idea for a New Model for Super-Conductivity
by
Josef Schintlmeister

Point of departure of the theory is the idea that the super-conducting electrons do not follow the Fermi statistics but follow Bose statistics and thereby for practical purposes it possesses the Maxwell velocity distribution. Two electrons unite during the forming of the super-conducting electrons when activated by a force in all three directions with easily-computed quantum-mechanical penetration of the potential barrier to a very loosely bound "bielectron". The binding is possible, since the magnetic attraction surpasses the Coulomb repulsion as early as a distance of 50-fold, classical electron-radii. Similar to the thermic disassociation of two-atomic gases, the temperature dependence of the number of super-conducting electrons can be reckoned. The zero energy point of the electrons which become free at the change of statistics with Fermi statistics is the cause of the increase of the specific heat in the super-conducting state; from this the momentary number of the super-conducting electrons can be determined in agreement with this computation. The disappearance of all the components of the electrical resistance (residual resistance, contact resistance, thermic part of resistance) is explained by the considerably larger electron wave-length of the super-conducting electrons; the electron wave-lengths are considerably larger due to the low zero-energy point. A sufficiently strong magnetic field directs the magnetic moment and thus destroys the binding. For the magnetically insensitive superconductors (e.g., PbBl, PbHg), the magnetic energy to be used at the absolute zero-point is equal to the thermic energy kT at the elastic point. Sufficiently inhomogenous electrical fields destroy or loosen the binding. Thus the super-conducting electrons cannot take part in the construction of the electron orbit of the atoms and the periodic, electrical field in the interior of the crystal lattice is decisive for the height of the elastic point and also decisive for the contingency of whether super-conducting electrons can be formed or not. The bielectrons have all the properties which were pre-supposed in the electrodynamic theory of super-conducting electrons by London and von Laue. This theory makes very obvious: the screening of external magnetic penetration of magnetic fields due to the induction of the permanent current, the finite depth-penetration of magnetic fields, the individual influence of the self-induction of the conductors for the current strengths in the branchings and also, if one takes into consideration the temperature dependence of the density of the super-conductor electrons and the Meissner-Ochsenfeld Effect.

To complete the discussion of superconductivity, it should also be mentioned that K. Alex Müller (Swiss, 1927–) and his student Johannes Georg Bednorz (German, 1950–) developed the first high-temperature ceramic superconductors, for which they won the Nobel Prize in Physics in 1987. Professor Gösta Ekspong of the Royal Academy of Sciences explained the importance of their work [https://www.nobelprize.org/prizes/physics/1987/ceremony-speech/]:

> The Nobel Prize for Physics has been awarded to Dr. Georg Bednorz and Professor Dr. Alex Müller by the Royal Swedish Academy of Sciences "for their important breakthrough in the discovery of superconductivity in ceramic materials". This discovery is quite recent—less than two years old—but it has already stimulated research and development throughout the world to an unprecedented extent. The discovery made by this year's laureates concerns the transport of electricity without any resistance whatsoever and also the expulsion of magnetic flux from superconductors. [...]
>
> Dr. Bednorz and Professor Müller started some years ago a search for superconductivity in materials other than the usual alloys. Their new approach met with success early last year, when they found a sudden drop towards zero resistance in a ceramic material consisting of lanthanum-barium-copper oxide. Sensationally, the boundary temperature was 50 % higher than ever before, as measured from absolute zero. The expulsion of magnetic flux, which is a sure mark of superconductivity, was shown to occur in a following publication.

Also for completeness, two other postwar discoveries in cryogenic electrical properties should be mentioned.

Klaus von Klitzing (German, 1943–, Fig. 6.132) discovered the quantum Hall effect, in which the electrical conductivity at the surface of a cryogenic semiconductor in a strong magnetic field can only assume integer multiples of a certain value. He won the Nobel Prize in Physics in 1985. Professor Stig Lundqvist of the Royal Swedish Academy of Sciences praised von Klitzing's discovery [https://www.nobelprize.org/prizes/physics/1985/ceremony-speech/]:

> von Klitzing studied the Hall effect under quite extreme conditions. He used an extremely high magnetic field and cooled his samples to just a couple of degrees above the absolute zero point of temperature. Instead of the regular change one would expect, he found some very characteristic steps with plateaus in the conductivity. The values at these plateaus can with extremely high accuracy be expressed as an integer times a simple expression that just depends of two fundamental constants: the electric elementary charge and Planck's constant which appear everywhere in quantum physics.
>
> The result represents a quantization of the Hall effect—a completely unexpected effect. The accuracy in his results was about one part in ten million, which would correspond to measuring the distance between Stockholm and von Klitzing's home station Stuttgart with an accuracy of a few centimeters. The discovery of the quantized Hall effect is a beautiful example of the close interrelation between the highly advanced technology in the semiconductor industry and fundamental research in physics. The samples used by von Klitzing were relined versions of a kind of transistor we have in our radios. His samples, however, had to satisfy extremely high standards of perfection and could only be made by using a highly advanced technique and refined technology. [...]

> von Klitzing's discovery of the quantized Hall effect attracted immediately an enormous interest. Because of the extremely high accuracy the effect can be used to define an international standard for electric resistance. The metrological possibilities are of great importance and have been subject to detailed studies at many laboratories all over the world.
>
> The quantized Hall effect is one of the few examples, where quantum effects can be studied in ordinary macroscopic measurements. The underlying detailed physical mechanisms are not yet fully understood. Later experiments have revealed completely new and unexpected properties and the study of two-dimensional systems is now one of the most challenging areas of research in physics.

Horst Störmer (German, 1949–, Fig. 6.132) discovered the fractional quantum Hall effect, for which he won the Nobel Prize in Physics in 1998. The Royal Swedish Academy of Sciences summarized his work [https://www.nobelprize.org/prizes/physics/1998/stormer/facts/] :

> The Hall effect refers to the fact that if an electrical current flows lengthwise through a metal band and a magnetic field is placed against the surface of the band at a right angle, a charge arises diagonally in the band. In interfaces in certain materials a quantum Hall effect occurs. Klaus von Klitzing discovered that changes in the magnetic field result in changes in what is known as Hall conductance that vary in steps of whole-number multiples of a constant. Subsequently, Horst Störmer and Daniel Tsui discovered in 1982 that there also are steps that represent fractions of the constant.

Klaus von Klitzing (1943–)
1985 Nobel Prize in Physics
Quantum Hall effect

Horst Störmer (1949–)
1998 Nobel Prize in Physics
Fractional quantum Hall effect

In the quantum Hall effect, the electrical conductivity of a semiconductor surface increases in "stair steps" as the strength of an applied magnetic field (B) is changed.

The fractional quantum Hall effect is similar but with smaller stair steps.

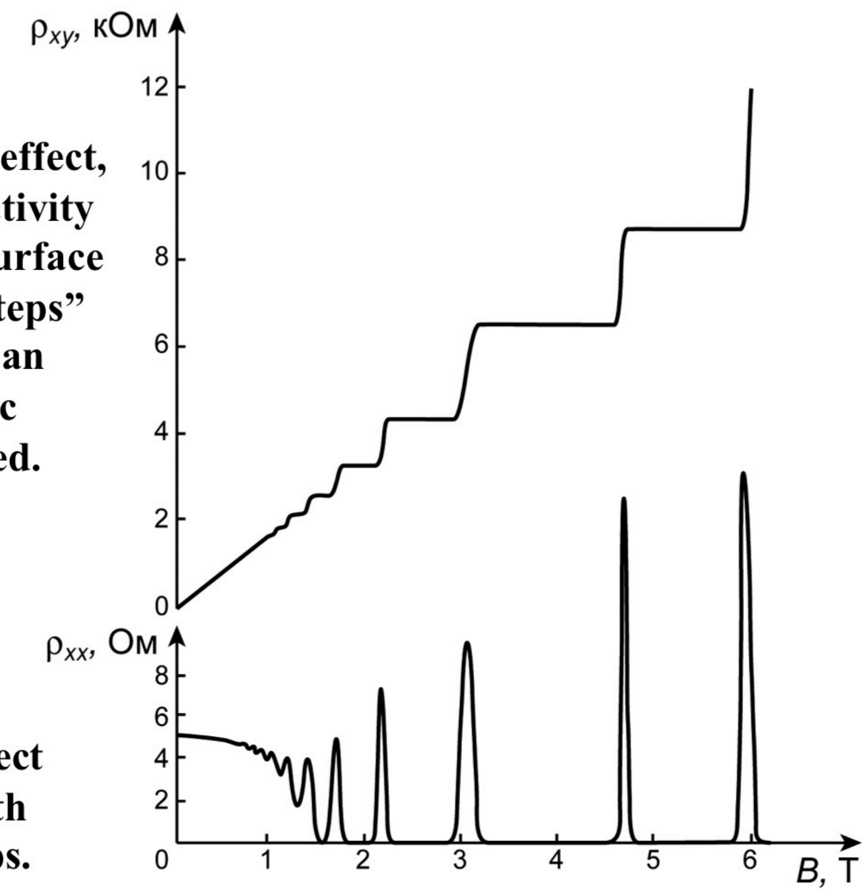


Figure 6.132: Klaus von Klitzing won the 1985 Nobel Prize in Physics for discovering the quantum Hall effect, and Horst Störmer won the 1998 Nobel Prize in Physics for the fractional quantum Hall effect.