Herbert F. Mataré

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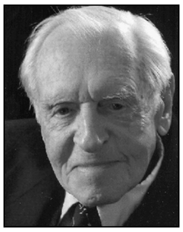
Editor: Thomas Haigh



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Physicist Herbert Franz Mataré has been doing groundbreaking work in the field of semiconductor research for more than 70 years. With Heinrich Welker in 1948, Mataré developed the first functional European transistor. (Their work occurred concurrently, but independently of the more recognized Bell Labs engineers.) After that, Mataré's company Intermetall was the first to demonstrate a battery-operated transistor radio. Since then, he has continued his cutting-edge research in semiconductor, electronics, and solar-power technology. With more than 80 patents and numerous publications,[1] Mataré's contributions to the field are only now being fully appreciated.

Early education

When Mataré was born in 1912 in Aachen, Germany, his grandfather was managing director of a large chemical company, and his father Josef was a well-known portrait painter. His mother taught mathematics before she married. Since his early youth, he enjoyed listening to classical music. At 11 years old, he built a radio receiver with lead-sulfide crystals and *cat's whiskers*, tiny metal wires that are moved by hand around a crystal to pick up radio signals. He became intrigued and fascinated by the fact that he could put together a detector receiver and thus capture several radio stations.

He received his secondary education at the local realgymnasium where he was mainly interested in sciences. After finishing high school, he was invited by his uncle to Switzerland and enrolled at the University of Geneva, where he studied physics, mathematics, and chemistry and earned a BS. He returned to Germany and pursued a master's degree at the Aachen University of Technology. In 1936, he was appointed assistant professor teaching physics and electronics. Three years later, he received his MS.

Professional career

In August 1939, with his diplomas in hand, Mataré applied for a job at Telefunken in Berlin. Among solid-state scientists, the basic chemical and physical properties of semiconductors were known. Research had been an academic pursuit for several decades, but scientists involved in radar technology began to realize that semiconductors might have a military and industrial potential as repeaters capable of replacing the vacuum tube. In 1933, Telefunken had set up a microwave department to produce radar systems. The miniaturization of vacuum tubes had reached technical limits and a solid-state equivalent was urgently needed. Research concentrated on ultra-high-frequency rectifiers, aiming at the development of an effective crystal mixer, based on recent advances in crystal rectifiers.[2]

The laboratory director assigned Mataré to concentrate on receiver technology, the construction of mixer stages, and the elimination of oscillator noise. Because the available magnetrons for 10-cm wavelength were inefficient, Mataré constructed a setup for noise measurement. His activity focused on improving the centimeter-wave receiver sensitivity, which above all, involved noise measurements. Mixer-diode noise was not well understood. He started with tests on vacuum diodes and crystal diodes. In 1942, the Technical University in Berlin awarded him a doctorate in physics. The following year, he applied for a patent on

Background of Herbert F. Mataré

Born: 12 September 1912, Aachen, Germany.

Education: Abiturium at Realgymnasium, Aachen 1932; University of Geneva, Switzerland (mathematics, physics, chemistry) 1933; Technical University Aachen (mathematics, theoretical physics, chemistry, electrochemistry, high-voltage engineering) 1939; Technical University Berlin (Dr Ing) 1942; Ecole Normale Supérieure, Paris (solid-state physics) 1950.

Professional Experience: Telefunken microwave laboratory, Germany, 1939–1945; F&S Westinghouse, France, 1946–1951; Intermetall, Germany, 1952–1953; Signal Corps Laboratory, 1954; Tung-Sol Electric, 1955; head of laboratory, Sylvania Corporation, 1956–1960; Lear Siegler, 1962; the quantum-electronics dept., Bendix Corp., Michigan, 1963–1964; assistant chief engineer, Missile and Space Systems Division, Douglas Aircraft, 1965; science advisor, Rockwell International, 1966–1969; visiting professor, California State University, Fullerton, 1970–1971; founder and president, ISSEC, 1970–2000.

Honors and Awards: Golden Ring, E. Rhein Foundation, Munich, 2008; Life Fellow, IEEE; Member Emeritus, New York Academy of Science; Honorary Member, Institute for the Advancement of Man; Member, American Physical Society; Member, Electrochemical Society.

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crystal diodes with electrolytic contacts. He also filed an application for crystal duodiodes for centimeter-wavelength mixers.[3]

In 1943, the laboratory was relocated to Leubus, Silesia, because of the bombing attacks on Berlin. When Mataré was able to obtain Germanium (Ge) diodes made by Heinrich Welker in Munich, it allowed him to make his first tests with semiconductor diodes. He used crystals with two whisker contacts, but the homogeneity of the crystals was unsatisfactory.

In 1944, while testing how to apply oscillator noise compensation with duodiodes made from crystal detectors, he found that a second whisker influenced the first barrier layer in certain crystals as proposed by Lilienfeld and Heil, who claimed a field influence. Mataré's research was not sufficiently advanced to decide whether it was a field effect or injection of minority charges.[4] He postulated that if there was some way to control the flow of electrons from one barrier layer to the other, it might produce amplification. Ge seemed better suited than silicon, since it was easier to purify because of its lower melting point. Under pressure to deliver working prototypes, however, he concentrated on improving a mixer based on silicon.

Postwar research

When the Russian army closed in, the Leubus site was abandoned and most of the equipment was lost. The personnel were transferred to Thuringia, where a new laboratory was set up. It was hardly in operation when American troops occupied the area and Mataré's research came to an end. He was given permission to join his family, and for several months, he worked as a farmhand in the fields (pp. 19–32).[5]

In 1946, by chance, he met a US Army officer who was setting up a military academy for servicemen wishing to continue their education. Given his background and his fluency in English, he was appointed to teach physics, mathematics, and chemistry to students from Harvard and other major schools. When the military academies closed, Mataré returned to the Technical University where he was appointed assistant professor of physics and electronics. On several occasions, British, French, and US officers of the Technical Field Information Agencies interrogated him about his research in semiconductors and radar.

In 1946, he was invited by the French Ministry for Technical Reconstruction to move to Paris and set up production of semiconductor diodes for use as rectifiers in radar. The German physicist Heinrich Welker accepted a similar offer.[6]

A small building located in Aulnay-sous-Bois, near Paris, was put at their disposal by the Compagnie des Freins et Signaux Westinghouse—no relation to Westinghouse Electric—a small company under contract with the Ministry of Post, Telegraph, and Telephone.

In the basement, Welker installed an high-frequency generator to heat the quartz tube in which the graphite holder with the Ge ingot was mounted. He set up test equipment to measure resistivity with a four-point probe and Hall-constants test for carrier mobility. He used a Bridgman-type furnace to cast pencil-like Ge rods, which were cut into small segments with a precision diamond saw.

On the first floor, Mataré installed the equipment needed to produce diodes and the test equipment to measure diode properties—namely, the I-V characteristics, base resistance, breakdown voltage, and frequency response. Some machine tools had to be made in-house. Two technicians, helped by several mechanics familiar with jewelers' lathes, built microwave test equipment. A microwave generator was purchased from a US company.

For the development of a functioning transistor, control of materials and technological execution are as important as the concept itself. An essential prerequisite for successful experiments was the availability of single crystals. Aside from diode production, Mataré resumed his research intended to eliminate the local oscillator noise in centimeter-wave mixer stages. He observed barrier-layer interference when duodiodes were tested for equal diode characteristics. He also noticed that in some cases he obtained injection and amplification when the crystal had been cut from a larger ingot.[7]

When Welker was able to acquire better-quality Ge, Mataré obtained an amplifier effect. Amplification was entirely dependent on the purity of the Ge. Mataré used grain boundaries to space the emitter-collector whiskers farther apart, which could only be done with monocrystalline surfaces. The fixation at submicron distances was difficult and tended to produce a short circuit. These observations allowed Mataré to gradually develop the theory of minority carrier injection.

When testing duodiodes for oscillator noise compensation with Ge crystals, he found that the current on one side increased when the other side was biased positively. The fixation at submicron distances had to be precise. He was able to keep point contact distances up to 100 microns by using a grain boundary (p-type core in n-type crystals) between the two whiskers to transport the emitter voltage to the junction on the other side. It was proof that minority injection was involved. He discussed the amplification with Welker who interpreted the result as a field effect, while Mataré was convinced it was due to a p-type zone in the crystal.[8]

Because the high-reverse voltage meant low impurity density of the crystal material, results improved gradually due to repeated remelting. With the development of crystal material from polycrystalline to monocrystalline Ge and silicon, diode production advanced to more stable and efficient rectifiers. When Welker was able to produce larger Ge crystals, Mataré obtained a better mass-to-surface ratio. By improving the purity of the Ge, he witnessed defect-electron conduction and thus the transistor effect with clear high-frequency amplification. Because Ge was easier to purify than silicon, he first realized minority-carrier injection with Ge.[9]

Mataré had designed holders for the use of a binocular microscope, which allowed a flexible adjustment of the whiskers with a good base contact to the crystal. It also involved making a low resistivity base contact and holders or fixtures where he could adjust the distance of the whiskers while measuring the transconductance, base resistance, and frequency behavior.

Some equalization of characteristics became feasible with crystals of a larger diameter and higher bulk-to-surface ratio, but the higher resistivity Ge barrier layer interference (minority injection) became a problem. Although these crystals were useless as mixer crystals, they became the first three electrode amplifiers. On the oscilloscope, one side changed when the other was tested, especially when one side was biased in reverse and the other in the forward direction.

This led Mataré to attach a high-frequency circuit on one side and to observe the signal strength on the other side. Clearly, this was due to carrier injection or p-type channeling. Progress was delayed because there was disagreement about the actual carrier flow. Welker maintained that it was due to a local field change, as he described in his 1945 patent application. He grew the crystals but did not participate in the tests and measurements and was not familiar with the mixer-diode problems of characteristics equalization.

Working together, Mataré and Welker often discussed the theory of superconductivity and gradually improved their understanding and problem-solving skills. Welker stuck to the amphoteric conduction theory of superconductivity, which he had developed as an assistant to Arnold Sommerfeld in Munich.[10]

The diode production began to work reproducibly at the end of 1947, but the crystals were still over-doped and Mataré asked Welker to change the design in order to obtain larger crystals. He found that the higher bulk-to-surface ratio improved the crystal structure and that there were more monocrystalline areas. This facilitated the search for equal characteristics of double diodes for microwave mixers. He also observed interference from one side to the other, as he had seen already during previous tests in Leubus.

Early in 1948, he observed for the first time amplification with duodetectors. He discovered that crystals with grain boundaries offered barrier layer interference at much wider distances than was possible on monocrystalline areas. This was the beginning of the *grain boundary transistor*, a precursor of the nanostructure devices. The diode and transistor-production was based on the ceramic holder design. Using grain boundaries as positive channels in June 1948, he achieved amplification over 100 microns distant whiskers. Painstaking and meticulous testing with increasingly ultra-pure Ge and the conversion to monocrystals finally resulted in a more regular amplifier effect.[11]

On 13 August 1948, the Compagnie des Freins et Signaux Westinghouse filed a patent application in France. The patent was granted in March 1952. On 11 August 1949, Welker and Mataré applied for a US patent, which was granted in March 1954 (see Figure 1).

Production of diodes increased rapidly. The amplifiers were sold to the PTT laboratory and the French military. PTT and CNET engineers mounted amplifiers and repeaters in experimental telephone lines and in radio and television receivers and transmitters. Mainly concerned with the development of atomic energy, the French government showed no interest in their work.[12]

On 18 May 1949, Eugène Thomas, secretary of the Ministry of Post, Telegraph, and Telephone, presented to the press two ''brillantes réalisations de la recherche française'' [brilliant realizations of French research]: the transistron and synthetic quartz. (*Transistron* was the French term for transistor.) The reaction was overwhelming; Herbert Mataré and Heinrich Welker were hailed as ''the fathers of the transistron.''[13]

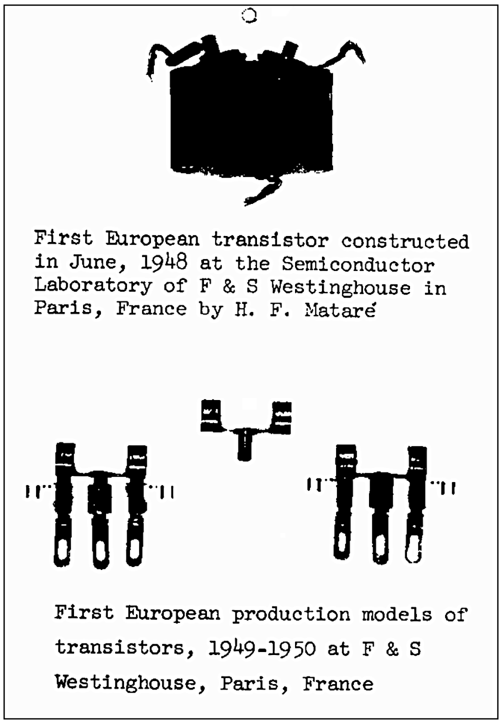

Figure 1. Photo image of Mataré's first transistor and production models. (Courtesy of Deutsches Museum Munich)

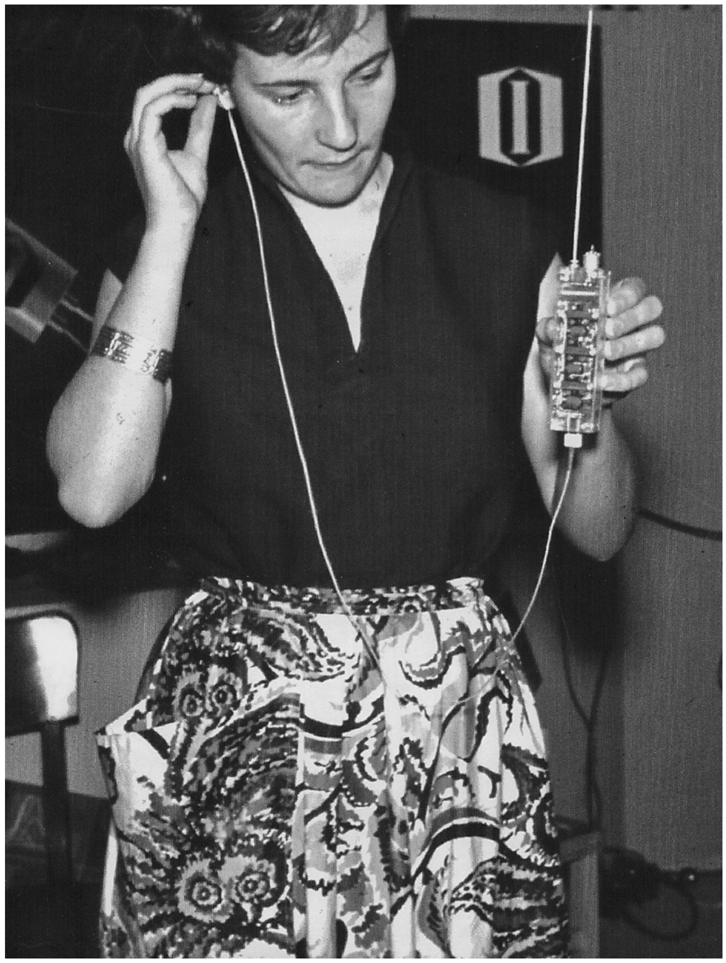

Figure 2. Demonstration of Intermetall's battery-operated transistor radio at the 1953 Düsseldorf Radio Fair.

In May 1950, Mataré attended the London Conference on the Physics of Semiconductors. The invention of the transistor by Bell Labs was the main topic on the agenda. He had long discussions with William Shockley, John Bardeen, and Walter Brattain. He also met with Karl Lark-Horovitz, who told him that thanks to German publications that he obtained through Swiss channels, he was well informed about the work done during the war in the field of solid-state physics. Shockley and Brattain flew from London to Paris and visited the laboratory at Aulnay-sous-Bois. They showed much surprise when René Sieur, chief engineer of the PTT, called a colleague in Algiers over a transistorized telephone line (p. 366).[2]

For several years, the French government had a practical monopoly, but it failed to recognize the potential of semiconductor technology. Despite the favorable reaction they had received in the press, Welker and Mataré were unable to obtain any additional financial support for their research. They realized they had no future in France and decided to return home. Welker joined Siemens where he continued his research on intermetallic III-V crystals.[14]

Through a French lawyer named Rechowski, Mataré came into contact with Josef Michael, the owner of DEFAKA, a chain of department stores. Being Jewish, Michael had migrated to the US. After the war, he had recovered his property, but exchange controls prevented him from converting his German marks into dollars. He supplied the funds that enabled Mataré to rent a building, buy machinery and equipment, and hire the necessary personnel. By the end of 1952, Mataré's company Intermetall was producing 2,000 diodes and 1,000 transistors a week (pp. 47–50).[5]

The transistor presented Intermetall's engineers with new challenges and opportunities. In September 1953, at the Düsseldorf Radio Fair, a young lady demonstrated to the public a tiny battery-operated transistor radio (see Figure 2). The housing was made of transparent Plexiglas, and the sound was amplified by four transistors and transmitted through an earphone.

The press, public, industry, and radio technicians marveled at the size and novelty. The magazine *Funk-Technik* noted,

> It seems the transistor has transcended the stage of an electronic component with interesting physical properties, and is being put to good use in areas that were until now the exclusive domain of the vacuum tube. At the Funkausstellung, an impressive number of applications are on display. It may be interesting for the radio technician to learn something about how transistors are manufactured.[15]

Shortly after the end of the Radio Fair, the German government lifted the ban on foreign currency. Mataré was told to stop production and to sell his company to Clevite Corporation. Because he was not allowed to conduct any scientific research in occupied Germany, he planned to move with his family to the US, hoping to resume his work in solid-state electronics.

Move to the US

Several years after the war ended, American intelligence officers were still looking for German scientists with advanced technical and scientific training. The Signal Corps was responsible for recruiting scientists, technicians, and engineers who were ready to share their expertise in exchange for a job and eventual US citizenship.

As he was preparing to leave for the US, Mataré received a letter from the Signal Corps inviting him to work at the Electronic Laboratory in Fort Monmouth. Through the Signal Corps, he came into contact with Tung-Sol Electric, a manufacturer of vacuum tubes located in Bloomfield, New Jersey. In 1955, he set up a laboratory for crystal growth and property measurements. The laboratory was almost ready to start a test production of diodes and transistors when a new manager decided to abandon the project. Mataré saw no future at Tung-Sol. Sylvania next offered to have him take over the semiconductor laboratory in Bayside, New York, where he stayed until 1960. The following year, the management of Bendix Corporation invited him to Southfield, Michigan, where he was put in charge of the laboratory for quantum electronics (pp. 57–59).[5]

Mataré noticed that many new companies engaged in cutting-edge technology were operating in California. In 1962, when the management of Lear Siegler offered him a position directing its laboratory, he moved to Santa Monica. The company was short of cash and unable to invest much in laboratory research. Management relied mainly on contract work, which allowed Mataré to establish good contacts with industry and with several government agencies in Washington (pp. 60–62).[5]

In 1965, Mataré set set up a laboratory at Douglas Aircraft in Santa Monica for electronics and headed a group of physicists and engineers with the task of installing working units for the most advanced topics in electronics. He organized a group to study cyclotron resonance in semiconductors and another group for optical heterodyne transmission combined with target-finding technologies. He also started work on microwave modulation of laser beams, a project that is still being discussed 40 years later (pp. 63–69).[5]

In 1970 to 1971, while he was teaching at the California State University, Fullerton, he was approached by North American Aviation (later Rockwell International) to come to Anaheim. There he supervised ongoing work and advised engineers and management.

He accepted an offer from the Globe Union laboratory in El Monte, California, to set up production of light emitters and solar cells. He drew up a detailed patent application for the construction of an epi-oven. Globe Union filed the patent application and shortly afterward terminated the employment contract. A compromise was reached by which he was given the right to use the patent in connection with his own projects (p. 70).[5]

Around the same time, he acted as consultant for Pyron Solar in La Jolla, California, which was active in building solar electric power plants. The energy crisis of the 1970s convinced him of the potential of solar energy and the need to end the over-reliance on finite coal and oil reserves. In 1971, he set up ISSEC, a consulting firm grouping scientists, technical specialists, marketing specialists, financial experts, and patent lawyers in the field of solid-state electronics, working predominantly in the fields of lll-V crystals, device problems and solar technology (p. 71).[5]

On 24 February 2003, John Markoff drew the public's attention to Mataré's contribution to the history of computing by publishing an article in the *New York Times*, titled "Herbert F. Mataré: An Inventor of the Transistor Has His Moment." Finally, the "French" transistor was rescued from oblivion.[16]

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