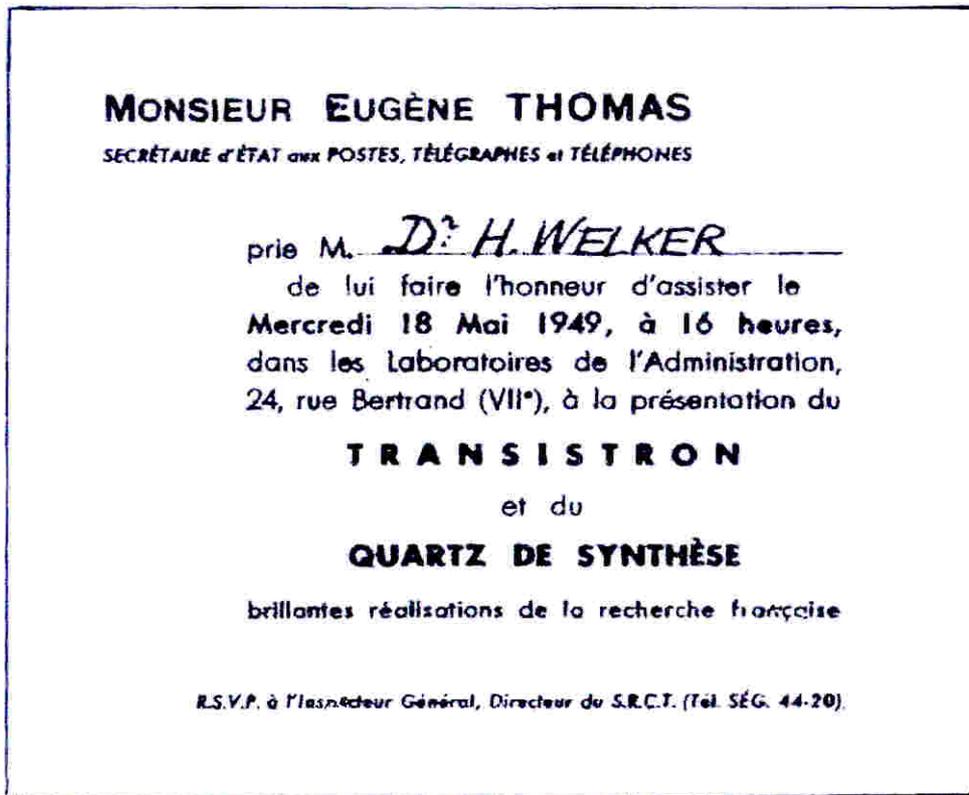


## THE "FRENCH" TRANSISTOR

*Armand Van Dormael*

On May 18, 1949, Monsieur Eugène Thomas, Secrétaire d'Etat aux Postes, Télégraphes et Téléphones, presented to the press two "*brillantes réalisations de la recherche française*": the transistron and synthetic quartz. The reaction was overwhelming. Two German scientists, Herbert Mataré and Heinrich Welker, were hailed as "the fathers of the transistron."



The newspapers reported that the transistron was an extraordinary achievement of French engineers. *Combat* carried a picture of Mr. Thomas holding in his hand a vacuum tube and a tiny ceramic device. The article read: "The transistor, an invention of the engineers of the Service des Telecommunications makes it possible to replace vacuum tubes in radio sets. The active principle of the "transistron" is a mineral - germanium - comparable to galena, but whose amplifying power is as good as the best vacuum tubes. Our picture shows the hand of the minister holding a vacuum tube and a much smaller "transistron". Besides, it consumes less current and lasts longer." The *Figaro* predicted that the "transistron" would be installed in radio and television transmitters and receivers, and in telephone lines.

For about three years Mataré and Welker had conducted experiments in the laboratory of F&S Westinghouse, a small French company located in the neighborhood of Paris. In 1946, the company had signed a contract with the Ministry of Post, Telegraph and Telephone. The government intended to modernize its telecommunications system and wanted a national supply of solid-state repeaters

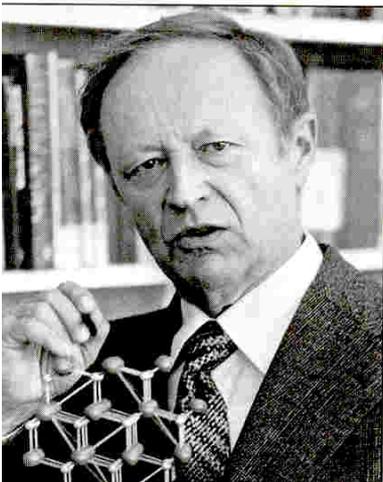
capable of replacing the vacuum tube relays in its telephony. The military were interested in semiconductor diodes for use as rectifiers in radar.

During the war, German and Allied researchers had been engaged in an intense race to develop ultra-high-frequency rectifiers. Radar technology had changed the nature of warfare by making it possible to "see" for hundreds of miles, even at night. Since French engineers had no competence in solid-state physics and in radar technology, the company hired two German scientists who were known for their war-time experience.

F. & S. Westinghouse put at their disposal a small empty building in Aulnay-sous-Bois, near Paris. The purpose was to establish a production line of diodes. Mataré and Welker were personally interested in developing semiconductor amplifiers. Their wartime research on ultra-high-frequency rectifiers had led them to the idea of a solid-state amplifier, but production pressure to deliver duodiodes for radar had prevented them from pursuing their experiments. Their collaboration allowed them to fill in the loopholes and blurred edges of semiconductor technology.

They set up a laboratory for advanced semiconductor research. Welker installed his HF generator in the basement. It served to heat the quartz tube in which the graphite holder with the germanium ingot was mounted. Three assistants kept the furnace in operation. He also installed a lab for the formation of graphite crucibles, the quartz tubes for the gas drying lines, attachments of tubing for hydrogen gas, test equipment to measure resistivity with a four point probe and Hall constants test for carrier mobility.

The first floor was filled with equipment needed for the production of diodes and for the measurement of diode properties: base characteristics, frequency response, mixer noise, capacity. A diamond saw for dicing was later replaced by a band saw. Together with Mataré, two technicians had built the instruments which were not available in the market. Welker grew the crystals, while Mataré concentrated on the testing, the production of diodes and advanced research. The second floor allowed for one rest room and two small living areas.



Heinrich Welker studied mathematics and physics at the University of Munich. For several years he was Assistant Professor working under Arnold Sommerfeld, one of the founders of modern theoretical physics. In 1940, he decided to shift from theoretical and fundamental research to practical solid-state physics and joined the Flugfunkforschungsinstitut Oberpfaffenhofen, a research institute dedicated to the application of microwave communications systems. There he experimented with ultra-high frequency radio waves.

In 1942, he returned to Munich University where he conducted experiments with germanium crystals for the purpose of achieving ultra-pure quality required for point-contact rectifiers and for the control of current in semiconductors. Schottky had brought him upon the idea of trying semiconductor detectors.

20.II.1942.

Dr.H.Welker.

Herrn  
Professor Dr.Schottky  
Berlin-Siemensstadt  
Wernerwerk/ZA

Sehr geehrter Herr Professor!

Vielen Dank für Ihren Brief vom 22.I.42, und die Sonderdrucke.

Nun zu den Fragen des Mehrkörperproblems. Bei dem Problem mit drei in einem gleichseitigen Dreieck angeordneten Atomen handelt es sich offenbar um eine Rechnung, deren Erweiterung auf das Benzolproblem mit sechs Atomen von London (Journal de Physik et le Radium 1937?) durchgeführt wurde und deren Erweiterung auf das Vielkörperproblem in Sommerfeld-Bethe, Hb. der Phys. Bd XXIV/II, Ziffer 12 als Anregung vom gebundenen Elektronenheer bezeichnet wird. London kommt in seiner Arbeit zu dem Ergebnis, dass im Benzolmolekül Ringströme um das ganze Molekül möglich sind, die auch den aussergewöhnlich grossen Diamagnetismus der benzolähnlichen Verbindungen erklären. Für die Erklärung der Supraleitfähigkeit und des vollständigen Diamagnetismus ist aber durch diese Rechnungen nichts getan. Denn mit zunehmender Atomzahl werden die Energieunterschiede zwischen den so gewonnenen Zuständen mit Elektronenumlauf zwar kleiner, so dass dieselben in der Grenze Atomzahl  $\rightarrow$  bereits beliebig schwache Magnetfelder zur Zerstreung des grossen Diamagnetismus ausreichen.

Der Begriff der inneren Ionisierungsenergie ist mir noch nicht sehr geläufig. Jedenfalls geht er über den Inhalt der Ziffer 12 wesentlich hinaus, in welcher ja sozusagen der metallische Zustand in den Rechnungen vorausgesetzt wird. Um die innere Ionisierungsenergie zu berechnen müsste man das London-Heitler-Heisenbergsche Modell der Metalltheorie heranziehen. Die weiteren Untersuchungen an diesem Modell durch Schubin und Wosonowski sind aber mathematisch sehr kompliziert und undurchsichtig und die Ergebnisse recht spärlich. Soviel ich mich besinne ist dort nur bewiesen worden, dass ein einziges freies Elektron existieren kann. Von der Existenz mehrerer freier Elektronen, wie sie der Fermi-Statistik genügen, oder gar von der Berechnung ihrer spezifischen Wärme war in dieser Arbeit keine Rede.

Ich glaube nicht, dass man mit diesem Modell noch viel weiter kommen wird. Es ist zu schwierig. Sympathischer sind mir schon die Betrachtungen von Byl, wobei ich nicht sicher bin, ob diese Arbeit nicht überhaupt ein Unsinn ist. Byl ordnet übrigens dem Grundzustand, ebenso wie Sie, eine konstante  $\psi$ -Funktion zu. Ueber die Bedeutung der "Ausweichmöglichkeiten" für die Fragen des Mehrkörperproblems ist wohl nur in der Dr.-Arbeit von Dessnandt publiziert worden, von der ich nur die erste Korrektur ohne Abbildungen besitze.

Zur Zeit wird bei uns über Ihre Sperrschichtprobleme experimentell auf breiterer Basis gearbeitet. Wenn Sie einen übrigen Sonderdruck Ihrer "Grundlagen" haben, so könnte ich diesen einem meiner Mitarbeiter geben.

We are experimenting extensively with your barrier layer problems at the present time. If you can send us an extra copy of your "Basic Principles", I would be able to give it to one of my assistants.

Bln-Siemensstadt, den 23. Juni 1943

Herrn Dr. H. Welker,  
Planegg b. München  
Karlstr. 10.

Lieber Herr Welker!

Heute möchte ich Ihren freundlichen Brief vom 27.5. kurz beantworten. Es freut mich, daß Ihre Detektorarbeiten zu einer Fertigung geführt haben, die hoffentlich später auch einmal friedensmäßige Bedeutung gewinnt. Ich hoffe auch, daß die Unterbringung der Fertigung bei Siemens Sie manchmal hierher führen wird und daß Sie mich dann besuchen.

Unter der "äußeren" Belegung der Doppelschicht habe ich auf S.8 des Lange-Briefes natürlich die im Halbleiter liegende verstanden.

Die den Widerstand der Randzone vergrößernde "Sperrschicht"-Bildung bei den Versuchen von Leo denke ich mir, wie Sie wohl auch verstanden haben, nicht durch eine Störstellenverarmung (chemische Sperrschicht) zustande kommend, sondern durch eine besondere Affinität der  $\text{Cu}_2\text{O}$ -Oberfläche für positive Ladungen; dadurch soll also eine physikalisch Randschichtwirkung in Form einer diffusen Doppelschicht entstehen, deren positive Belegung **auf** der Oberfläche sitzt, während die negativ Belegung durch die verteilte Raumladung der negativen Störstellen geliefert wird.

Zum Studium Ihrer Supraleitungsarbeit bin ich noch nicht gekommen, freue mich aber schon darauf.

Mit herzlichen Grüßen

Ihr

*W. Schottky*

I am pleased to know that your work on detectors has reached the production stage, and I hope that one day it will be of use for important peaceful purposes.

Herrn

Dr. W e l k e r,  
M ü n c h e n.  
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Lieber Herr Welcker!

Haben Sie vielen Dank für Ihren Brief. Über Ihre Theorie der Supraleitfähigkeit haben wir hier schon viel diskutiert und natürlich auch mancherlei Wenn und Aber gefunden. Was den Einwand betrifft, den ich seinerzeit Herrn Prof. Sommerfeld gesagt hatte, hat mich Ihr Brief ziemlich beruhigt. Es gibt aber noch andere Bedenken, über die ich aber noch ausführlich mit Hund sprechen möchte, bevor ich Ihnen schreibe; denn Hund hat sich mit dem Problem der Supraleitung noch mehr beschäftigt als ich selber. Sie werden also in einiger Zeit noch einen weiteren Brief über die ganzen Fragen bekommen.

Wie geht es Ihnen eigentlich sonst in München unter Ihrem neuen Chef? Sollten Sie irgendwelche Schwierigkeiten haben, bei denen ich Ihnen helfen kann, so stehe ich Ihnen natürlich gern zur Verfügung.

Mit vielen Grüßen auch an Professor Sommerfeld  
Ihr

*H. Leisnerberg.*

We have had many discussions about the theory of superconductivity, and obviously also found many « ifs » and « buts ». Your letter has reassured me concerning the doubts I expressed to Professor Sommerfeld. But I have other reservations about which I want to talk to Hund before I write you, because Hund has concerned himself more extensively with superconductivity than myself.

They discussed extensively the impact of impurities, both on the surface of semiconductors and inside. Welker was granted a patent for a point-contact rectifier for high-frequency electromagnetic waves. It was the beginning of a new materials science: solid-state physics and applied crystallography.

In 1945, shortly before the end of the war, he completed his research and applied for a patent relating to the use of electron currents in germanium or silicon for control purposes. It was the first time a process of this kind had been suggested. In the document he refers to Heil's and Schottky's concepts and to Pohl's and Hilsch's patents. He describes in detail the various experiments he conducted over a period of several years. The materials mentioned in the patent application are silicon and germanium. He mentions specifically that he considers these materials as semiconductors and not as metals. In the patent he formulated the theory of the field effect, but was unable to obtain transconductance in laboratory tests. After the war, until 1955, scientists were not allowed to pursue their research in occupied Germany. That same year, Welker repeated his patent application. Because of high-powered pressures, it took until 1973 for the patent to be granted.

From 1946 to 1951, together with Herbert Mataré, he worked at the F&S Westinghouse laboratory. Welker concerned himself with the purification of germanium and experimented with cutting-edge crystal growing. Despite the positive and promising results, when the French government launched its nuclear power program, the semiconductor project was scrapped and left to private companies.

Welker returned to Germany and joined the Siemens' research laboratories in Erlangen, where he stayed until his retirement in 1977. There he identified the potential of intermetallic III-V compounds as semiconducting components, paving the way for microwave semiconductor elements as well as luminescent and laser diodes. The III-V compound semiconductors are now part of most cell-phone and optical TV channels and will be an essential part of the future high bandwidth fiber communications.

His pioneering research into gallium arsenide laid the scientific foundations for the development of light-emitting diodes. If these tiny low-power luminaries can be commercially produced, the light bulb may face stiff competition. Welker did not live to see the results and witness the impact of his work. In 1976, Siemens set up the Heinrich Welker Memorial Medal for contributions to the field of III-V compound semiconductor development.



Herbert Mataré studied mathematics, chemistry, electrochemistry, nuclear physics and solid-state physics at the Technical University in Aachen where he graduated as Diplom-Ingenieur in applied physics. He also studied mathematics, physics and chemistry at the University of Geneva. In 1939, he joined the Telefunken laboratory in Berlin, at a time when it became obvious that the miniaturization of vacuum tubes had met a technical limit and that a solid-state equivalent was urgently needed.

His work was hampered by massive air raids on Berlin, where the workshops that made the gold-plated cavities and precision couplers were located, making commuting extremely dangerous.

In 1943, Telefunken established a plant in Leubus, Silesia. There his research focused on the improvement of the cm-wave receiver sensitivity. This involved above all noise measurements. Mixer-diode noise was not well understood. It was while testing oscillator noise in detector receivers and compensation of oscillator noise by the use of duodiodes that he first worked with double-whisker semiconductor crystals and found that he could influence a barrier layer by a second electrode while equalizing both detectors. In 1942, he published the results which showed that oscillator noise was reduced in the so-called push-pull operation where the intermediate frequency does not contain the oscillator noise. He thus made his first tests with semiconductor diodes. Crystals with two whisker contacts, called "three-electrode crystals" were used, but their homogeneity was insufficient.

He was familiar with the patents granted to Lilienfeld, Schottky, Heil and Pohl. Based on the progress made by German scientists over a period of several decades, he was able to refine and focus his research on ultra-high-frequency rectifiers using known compounds like silicon-carbide and lead-sulfide. But the crystal material then available was insufficiently homogeneous. Yet, he was able to measure the favorable noise values at the cm-wavelength as compared to vacuum diodes.

He tried double-point semiconductor diodes as mixers, to eliminate the oscillator noise in receivers. He did not have the time to concentrate on barrier layer interaction research, since he had to deliver mixer diodes for receivers and construct sensitivity test emitters. Highly doped silicon crystals were much better suited for diode mixers than highly purified germanium diodes. Rectification of such frequencies did not work with high barrier capacities. Germanium point-contact diodes had a higher capacity than silicon diodes, because of the larger space charge. Recovery time was much better with highly doped silicon detectors.

While testing how to apply oscillator noise compensation with duodiodes made from crystal detectors, he found that a second whisker could influence the first barrier layer in certain crystals as proposed in the patents by Lilienfeld and Heil, who claimed a field influence. His research was not sufficiently advanced to decide whether it was a field effect or injection of minority charges.

In microwave detection, silicon had the advantage in terms of internal resistance as well as capacity. For space-charge injection, the higher purity of germanium resulted in a wider space-charge. He figured that if there was some way to control the flow of electrons from one barrier layer to the other, it might produce amplification. Germanium thus seemed a better candidate for amplification than silicon. Germanium was easier to purify because of its lower melting point.

In 1944, as the Russian army closed in, the site and most of its equipment were abandoned and the operation was transferred to Thuringia. The new laboratory 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, in exchange of food.

Fortunately, the US Army organized college level courses at a military academy in Wabern, near Kassel, where he taught physics and mathematics to students from Harvard and other American universities. For some time he also taught at Aachen University. He was repeatedly interrogated by American, British, and French technical information agencies about his work on radar during the war years. At one such meeting, he was invited to Paris to build a semiconductor diode plant. Having studied in Geneva, he spoke French very fluently and gladly accepted the offer, indicating that he would also want to continue his work on crystal amplifiers.

Mataré had lost his laboratory notes but had his findings in mind when he arrived in Paris to organize with Welker the production of diodes. Both wanted to pursue the research on duo-detector mixers. Their wartime experience allowed them to refine their tests and to develop a better understanding of cause and effect. Welker used a Bridgman-type furnace to cast pencil-like germanium rods. It required two or three assistants to keep the furnace in operation. The melt sustained a higher concentration of impurities than the crystals. As the heat went through the crystal, impurities were collected in the melt and the crystalline material left behind was of higher purity. The process worked for germanium, but not well for silicon which required higher temperatures.

Initially he used the same process he had applied in Munich. He grew the germanium crystals in fine quartz tubes in the form of pencil lead. They needed only to be cut into fine plates in order to be solderable directly into the diode fixture. But the purity of the crystals was insufficient because of the high surface/bulk ratio and thus useless for the high blocking voltages required by the PTT.

Traces of impurity affect the conductive properties of germanium. The nature of the impurities and their concentration in the material must be rigorously controlled in order to make the electrical properties predictable and the germanium suitable for transistor manufacture.

Mataré did the measuring and the testing, while concentrating his research on the minority carrier injection process. Three mechanics had built and maintained the instruments. Mataré had to supervise the work of six electrical engineers who did the measuring, while about ten girls did the testing and several others took care of the shipment of diodes.

The key to the development of the transistor was the understanding of the process of electron mobility in a semiconductor. This was a highly complex operation. He had designed the holders by using 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 - to be tested independently - and holders or fixtures where he could adjust the distance of the whiskers (microns), while measuring the transconductance, base resistance and frequency behavior. Part of this was a pulse generator to fix the contacts by a thermal transit pulse. Such test stations had to be designed and built in-house.

The surface around the whiskers had to be stabilized with epoxy. In addition, duodiodes for use in radar - which had no amplification action - had to be equalized on the oscilloscope and in a mixer circuit for cm-waves. This and the cm-wave mixing circuit had also to be built in-house. Mataré made the design which was executed by two high-precision mechanics who used jewelers' lathes for the purpose.

In 1946, they started production of germanium diodes. This required high-reverse voltage, meaning low impurity density of the crystal material. Welker now obtained crystal material from Munich, which he tried to purify by re-melting in pure graphite. Mataré suggested that he grow larger-size boules. In 1947, he tested duodetectors for balanced mixers. He had developed the method during the war and had found that he could influence one detector side with the second whisker. But at that time his immediate project was noise reduction in mixer stages and building a test sender for sensitivity measurements.

Testers had to be built which allowed to form the contact by a voltage pulse and to observe the result on an oscilloscope. As these diodes had to be formed for various applications, he also had to build testers for the recovery time - after pulse injection - and the noise level.

Pursuing his research started in Silesia, he constructed duodiodes which had to be equalized on the oscilloscope. With better crystals (larger diameter, higher bulk/surface ratio) some equalization of characteristics was feasible but with higher resistivity Ge barrier layer interference (minority injection) became a problem. While the crystals were useless as mixer crystals, they became three-electrode amplifiers. During the tests 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. When he attached a high-frequency circuit on one side, he observed the signal strength on the other side. It became clear that this was due to carrier injection or p-type channeling.

Mataré was familiar with Schottky's theory and used his formula for the barrier to calculate the capacity. Schottky mentioned defect-electrons because the differently conducting semiconductors were known, but not their interference in one and the same crystal. That became clear to Mataré in 1948, when he was able to inject minorities and achieve amplification. The theory was developed when he understood that the grain boundary was actually a nanostructure with high p-type conductivity.

When testing duodiodes with germanium crystals, he was able to measure amplification. He found that the current of one side increased when the other side was biased positively. 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. In *L'Onde Electrique* of November 1950, he described the 'interaction resistance' showing the right polarity or the bridge of positive charges, which caused the reverse current of the second whisker to increase. The fixation at sub-micron distances is very difficult and sensitive to a short circuit. He was able to keep point contact distances up to 100 microns. This was possible because he used a grain boundary (p-type in n-type crystals) between the two whiskers to transport the emitter voltage to the junction on the other side. It was also proof that minority injection was involved.

He observed that crystals with grain boundaries offered barrier layer interference at much wider distances than was possible on monocrystalline areas. This was the birth of the "grain boundary transistor", a precursor of the nanostructure devices.

As the high-reverse voltage meant low impurity density of the crystal material, results improved gradually due to repeated re-melting. With the development of crystal material from polycrystalline to monocrystalline germanium and silicon, diode production advanced to more stable and efficient rectifiers. When they were able to produce larger germanium crystals, they obtained a better mass/surface ratio. By improving the purity of the germanium, they obtained defect-electron conduction and thus the transistor effect with clear high-frequency amplification. As germanium was easier to purify than silicon, it was with germanium that minority-carrier injection was first realized.

Painstaking and meticulous testing with increasingly ultra-pure germanium and the conversion to monocrystals finally resulted in a more regular amplifier effect. By January 1948, the tests were probative. The first germanium devices with a negative Hall coefficient capable of amplification were realized in July 1948. The diode and transistor production was based on the ceramic holder design. Manufacturing started immediately. The total production was sold to the French telecommunications laboratories and the military. On August 13, 1948, Westinghouse applied for a French patent which was granted on March 26, 1952.

**BREVET D'INVENTION**

Gr. 12. — Cl. 6.

N° 1.010.427

**Nouveau système cristallin à plusieurs électrodes réalisant des effets de relais électroniques.**Société anonyme dite : COMPAGNIE DES FREINS ET SIGNAUX WESTINGHOUSE  
résidant en France (Seine).**Demandé le 13 août 1948, à 15<sup>h</sup> 44<sup>m</sup>, à Paris.**

Délivré le 26 mars 1952. — Publié le 11 juin 1952.

*(Brevet d'invention dont la délivrance a été ajournée en exécution de l'article 11, § 7,  
de la loi du 5 juillet 1844 modifiée par la loi du 7 avril 1902.)*

On connaît déjà des systèmes cristallins permettant d'assurer la commande et/ou le contrôle de courants électriques à l'aide d'un semi-conducteur solide grâce à l'utilisation d'une ou plusieurs électrodes de commande, soit dans la couche d'arrêt ou de blocage dudit semi-conducteur (voir par exemple l'addition n° 38.744 du 3 juillet 1930 au brevet français n° 649.432 du 28 janvier 1928, le brevet français n° 866.372 du 5 octobre 1942), soit au voisinage immédiat des couches semi-conductrices avec un isolement approprié (voir le brevet français n° 786.454 du 1<sup>er</sup> mars 1935).

Mais les difficultés de réalisation industrielle de tels systèmes furent telles qu'ils durent être abandonnés ou que leur développement est resté pratiquement limité à de simples modèles expérimentaux ou à des curiosités de laboratoire. On pourra consulter, à l'appui de cette affirmation : Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, rapport annuel de R. W. Pohl 1933/34, p. 55; Schweizer Archives 1941, cahiers 1 et 3, Ueber Sperrschichten par W. Schottky; Zeitschrift f. Physik, volume 111, cahiers 5 et 6, 1938 (R. Hilsch et R. W. Pohl); Modern Theory of Solids, 1940 (F. Seitz); Crystal Rectifiers, 1948 (H. C. Torrey et C. A. Whitmer).

Pour réaliser pratiquement des systèmes comportant des semi-conducteurs solides agencés pour produire un ou des effets de relais électroniques similaires à ceux qu'on observe dans les lampes électroniques, il est nécessaire de résoudre deux difficultés. La première consiste dans le fait que le diamètre de la surface de contact entre l'aiguille métallique et le cristal doit être d'un ordre de grandeur correspondant à celui de l'épaisseur de la couche d'arrêt du cristal. La seconde consiste dans le fait que l'écartement

entre les électrodes conductrices, au point de contact avec le semi-conducteur, doit être choisi de telle sorte que l'une des pointes d'électrode conductrice soit située dans la zone de la couche d'arrêt de l'autre pointe.

Avec les couches d'arrêt les plus épaisses qui ont pu être réalisées jusqu'ici, il aurait fallu prendre comme diamètre des surfaces de contact, d'une part, comme écartement des deux pointes, d'autre part, des valeurs inférieures à 5  $\mu$ . Si la première condition est réalisable, à condition de placer une aiguille sur un cristal sous une pression inférieure à 10 gr. par exemple, la seconde se heurte par contre à de très grandes difficultés mécaniques.

On a bien essayé de trouver des dispositions de semi-conducteurs à trois électrodes de dimensions macroscopiques. Mais, pour obtenir un effet de commande décelable, il faut choisir un cristal d'une concentration électronique ou à concentration de défaut électronique tellement faible que la résistance interne du dispositif, devient très élevée, ce qui rend les applications techniques absolument impraticables.

La présente invention due aux travaux des Docteurs Henri Welker et Herbert-Francois Mataré, permet de résoudre toutes ces difficultés et de porter sur le plan des réalisations industrielles de tels systèmes cristallins à plusieurs électrodes réalisant des effets de relais électroniques.

Ladite invention est essentiellement caractérisée par le fait qu'on associe dans un système à plusieurs électrodes au moins deux semi-conducteurs cristallins à caractères de conductibilité différents dont l'une des électrodes semi-conductrices constitue l'électrode de commande et comporte une couche d'arrêt ou de blocage superficielle.

On April 21, 1948, Mataré applied for a patent in the United States, which was granted on May 8, 1951.

Patented May 8, 1951

2,552,052

## UNITED STATES PATENT OFFICE

2,552,052

### PUSH-PULL CONVERTER OF THE CRYSTAL TYPE FOR ULTRA-SHORT WAVES

Hébert François Mataré, Vaucresson, France, assignor to Société Anonyme dite: Compagnie des Freins et Signaux Westinghouse, Paris, France

Application April 21, 1948, Serial No. 22,307  
In France May 23, 1947

5 Claims. (Cl. 250-20)

1

The present invention relates to rectifiers and, more particularly, to push-pull connected rectifiers of the crystal type employed in systems using ultra-short electric waves.

It has been known for some time that the use of push-pull connected rectifiers as detectors or mixers in systems of the character described is very advantageous, for example in the case of mixer stages for the superheterodyne reception of ultra-short carrier waves wherein, upon suitable coupling of the outputs of the antenna and of the local oscillator to the input of such stage, the radiation of the oscillator output by way of the antenna will be prevented. It is also known that, in the case of ultra-short waves of the order of ten centimeters or less, the use of rectifiers of the crystal type is very desirable. Heretofore, however, it has not been practicable to arrange rectifiers of this type as a unit suitable for push-pull operation, this being due to the fact that known methods of producing such rectifiers do not result in rectifier elements having exactly identical characteristics which is an indispensable condition for the satisfactory functioning of a push-pull type detector. In addition to perfect symmetry, the requirements for a detector or modulator suitable for ultra-short waves also include very short inter-electrode connections and extremely low distributed capacitances.

It is, therefore, an object of the present invention to provide a rectifier of the character described which meets the above requirements.

Another object of the present invention is to provide a push-pull type mixer or modulator for ultra-short waves.

A further object of the invention is to provide a crystal type rectifier adapted to be used in combination with a modulator stage of the resonant cavity type.

According to a feature of the invention, a rectifier for ultra-short waves comprises a pair of composite layers on a metal base plate and a pair of connecting electrodes each contacting one of said layers at substantially one point only.

According to another feature of the invention, a rectifier of the character described has a pair of connecting electrodes coupled capacitively to spaced portions of a cavity resonator.

The above and other objects and features of the invention will become apparent from the following description, reference being had to the accompanying drawing in which:

Fig. 1 illustrates a push-pull crystal detector according to the invention, shown in elevational cross section;

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Fig. 2 is an end view of the detector shown in Fig. 1;

Fig. 3 is a diagram showing the equivalent circuit of the detector illustrated in Figs. 1 and 2; and

Fig. 4 shows the detector of Fig. 1 combined with a mixer stage of the resonant cavity type designed for ultra-short waves.

Referring first to Fig. 1, there is shown a metallic base plate 1 serving as a cathode and provided with a spring or contact element 2. The opposite faces of this base plate 1 are provided with composite crystalline layers 3a, 3b, respectively, of equal thickness, these layers having outer surfaces forming barrier layers or barrier surfaces. The formation of these barrier layers may be carried out by any known method and preferably takes place in a single operation. The composite layers may be produced by precipitating crystalline needles directly upon layers of germanium, silicon, copper or other semiconductive material, for example, by methods utilized in the manufacture of rectifiers of the copper oxide type, as by vaporization of a suitable material or by electrolytic deposition. It is actually possible to produce composite layers of predetermined and identical properties on both sides of the metal base plate in the course of a single operation. In accordance with the invention, the two layers are embedded in the metal base 1 in such a manner that the series resistance thereof becomes as small as possible.

The two connecting electrodes or anodes 4a, 4b are formed by providing bodies 6a, 6b of insulating material having conical cavities and filling these cavities with a substantially non-oxidizable metal such as tin, copper, silver, gold and so forth. The insulating pieces 6a, 6b should be of the highest quality in regard to the frequencies utilized, that is to say they should consist of a dielectric material having low inductivity and a small loss factor. They may consist of ceramic material such as steatites or they may consist of synthetic resins or other material which is capable of withstanding ultra-high frequencies.

It is clear that the process of filling and the type of metal employed for the electrodes 4a, 4b will vary depending on whether one or the other of the above classes of insulating material are used, in view of the thermal and mechanical differences between these materials. In the case of a steatite, it will be possible to use a metal having a relatively high melting point and to pour the same into the cavity. It will also be possible to use a metal in comminuted form and to

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compact the particles by a baking or fusing process. In the case of synthetic resins, if the electrode material is to be poured, a metal or alloy of relatively low melting point should be used. It will likewise be possible to use a mechanical process similar to riveting or hammering. Generally, any suitable technological process may be employed in the formation of the electrodes 4a and 4b.

The metal base plate 1 which supports the two crystalline layers 3a, 3b constitutes the desired very short connection between these layers; at the same time it acts as a mutual screen between the two anode electrodes 4a and 4b, thus effecting a reduction of the capacitance  $C_a$  (Fig. 3) existing between these electrodes. It will be understood that the member 1 may be dimensioned in such a manner that the resulting inter-electrode capacitance will have the value required to tune the rectifier assembly to a desired resonance frequency, which may be of particular interest in the case of detectors or modulators for ultra high frequencies.

As shown in Fig. 2, the detector is assembled as a unit which is centrally symmetrical with respect to the axis O, except for a projection 1 provided on the base plate 1. This projection is a convenient means for effecting a cathode connection with the aid of the contact element 2, such a connection being of particular interest in the case of an assembly such as that illustrated by way of example in Fig. 4.

Fig. 3 represents the equivalent circuit diagram corresponding to a push-pull detector according to the invention. Therein,  $D_1$  and  $D_2$  are ideal unidirectional conductors or rectifiers devoid of any losses of capacitance;  $R_1$  and  $R_2$  are the ohmic resistances preferably including any external resistances to be considered in connection with the impedance of the system;  $C_1$  and  $C_2$  are the parallel capacitances;  $R_1'$  and  $R_2'$  are the respective series resistances which exist at the boundary layers and are due to the contact between the semi-conductor and the counter-electrode. It will be noted that the magnitudes of  $R_1$ ,  $C_1$  and  $R_1'$  associated with  $D_1$  are equal, respectively, to the magnitudes of  $R_2$ ,  $C_2$  and  $R_2'$  associated with  $D_2$ , owing to the arrangement according to the invention. Finally  $C_a$  represents the external capacitance whose absolute value may be appreciably reduced by virtue of the arrangement herein proposed.

It will be appreciated that a push-pull detector according to the invention offers not only the advantage of suppressing the radiation of the oscillator output by way of the antenna, but also effects a suppression of the background noises of the oscillator.

The use of the detector described is particularly advantageous in connection with oscillatory circuits using resonant cavities. In such a case it will be possible to obtain high-frequency coupling between the two anode electrodes 4a and 4b on the one hand and adjacent plates or elements of the cavity resonator on the other.

Fig. 4 shows schematically a mixer stage for ultra-short waves comprising an oscillatory circuit utilizing a resonant cavity.

The cavity resonator 8, having the cross section of a flattened cylinder, is excited by the received wave through an antenna loop 9. As a result there will be set up alternating potentials of opposite phase on the plates 10a, 10b which form the flattened portions of the cavity, relative to the potential obtaining in the plane of symmetry.

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The two electrodes 4a and 4b of the detector, disposed at opposite sides of the axis of symmetry of the resonator, are capacitively coupled to the plates 10a, 10b, respectively, by means of armatures 11a and 11b; on the other hand, these electrodes are also connected by means of two coaxial conductors 12a and 12b to a push-pull connected intermediate-frequency device (not shown). The oscillator frequency is supplied by the generator 13, by way of a line 14, to the plane of symmetry represented by the base plate 1 which supports the crystalline semi-conductive layers.

It will thus be seen that the detector is driven in push-pull by the received frequency and in parallel excitation by the oscillator frequency, the intermediate frequency being extracted in push-pull.

The forms of the invention specifically shown and described herein are given merely by way of illustration and not as a limitation upon the scope of the invention and defined in the appended claims.

What is claimed is:

1. A push-pull rectifier of the crystal type for ultra short electric waves, comprising a metal base plate, a pair of electrically identical semi-conductive layers on opposite faces of said base plate, the outer part of said layers forming barrier layers, a pair of connecting electrodes each making contact directly with one corresponding barrier layer at substantially one point only, a third electrode connected to said base plate and bodies of insulating material embedding respectively each of said pair of electrodes and overlying respectively each of said barrier layers and the major portion of the surface of said base plate on which is mounted the corresponding semi-conductive layer.

2. A rectifier according to claim 1 wherein said connecting electrodes are of substantially conical shape bearing with the pointed ends upon said barrier layers, respectively.

3. A push-pull rectifier of the crystal type for ultra-short electric waves, comprising a metal base plate having two parallel faces each provided with a recess, said two recesses being of the same depth, a semi-conductive layer embedded in each of said recesses, the outer part of said layers forming barrier surfaces, a pair of bodies of insulating material each in contact with one corresponding barrier surface and overlaying the major portion of the corresponding surface of said base plate in which are inserted said semi-conductive layers, each of said bodies being provided with a substantially conical cavity open at its pointed end toward the barrier surface of the corresponding semi-conductive layer, and a pair of substantially conical connecting electrodes each filling one of said cavities and conductively contacting the barrier surface of said corresponding semi-conductive layer at said pointed end.

4. A modulator stage for ultra-short waves, comprising a cavity resonator, input means adapted to apply an electric wave in opposite phase to spaced portions of said resonator, a rectifier according to claim 1 disposed in said resonator, coupling means capacitively coupling each of said connecting electrodes to a respective one of said spaced portions, a source of oscillations, connector means arranged to apply said oscillations between said base plate on one hand and said two portions in parallel on the other, and output means connected in push-pull across said connector electrodes on one hand and said spaced portions on the other.

May 8, 1951

H. F. MATARÉ  
PUSH-PULL CONVERTER OF THE CRYSTAL TYPE  
FOR ULTRA-SHORT WAVES  
Filed April 21, 1948

2,552,052

FIG 1

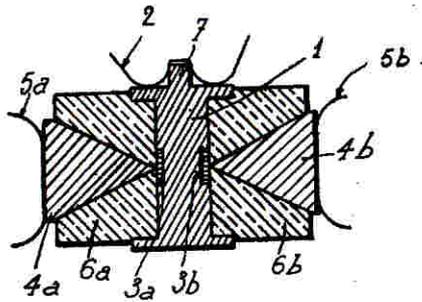


FIG 2

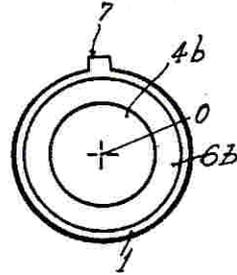


FIG 3

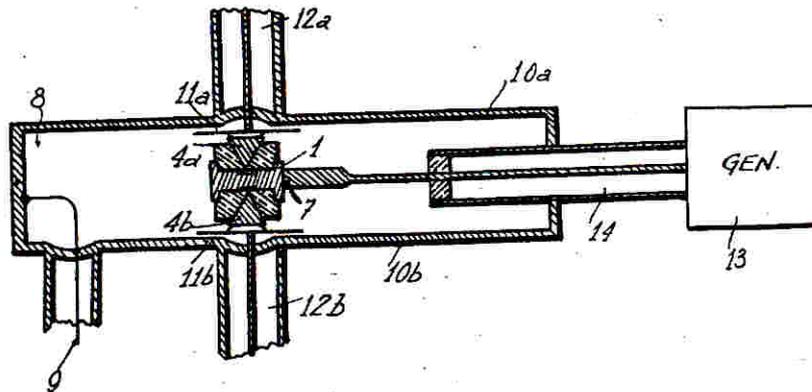
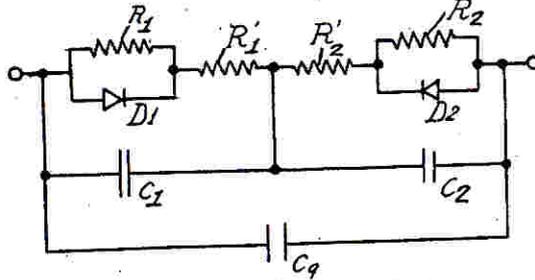
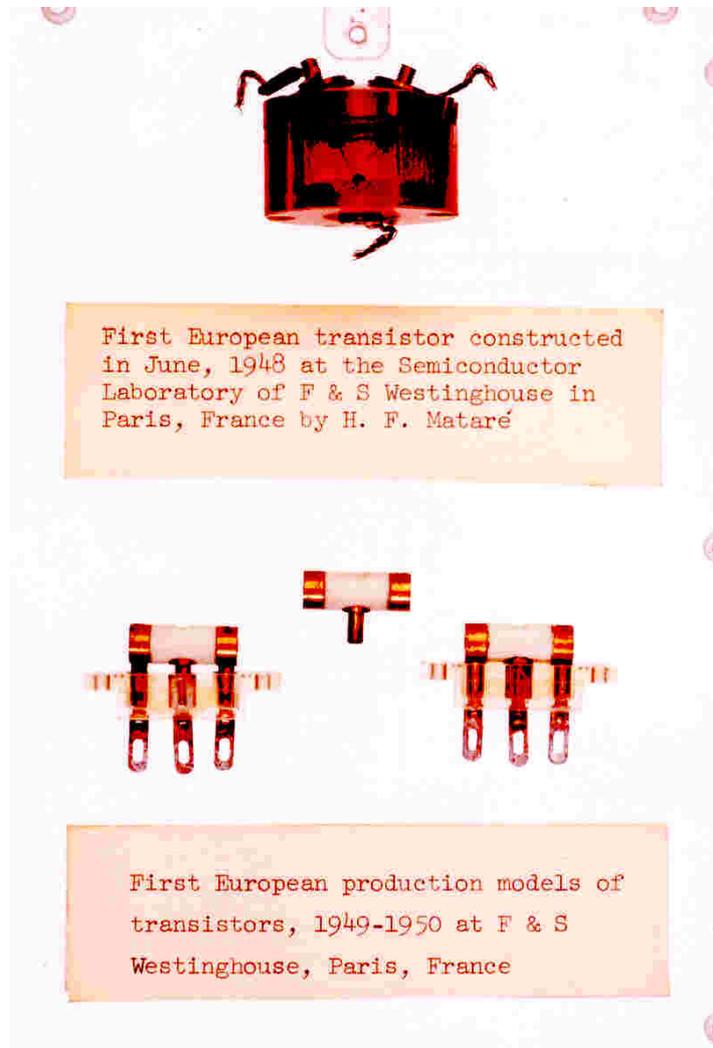


FIG 4

INVENTOR:  
Herbert Francois Mataré  
By: *John W. Gray*  
His Agent

He referred to the use of duodetectors for microwave mixers and to the similarities of the technologies used in microwave radar and in the crystal amplifier. On August 11, 1949, Mataré and Welker filed a patent application for the invention of "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, or closely adjacent to semiconductive layers with a suitable insulator interposed therebetween." (Claims priority, application France August 13, 1948.) The patent was granted on March 30, 1954.

In the spring of 1949, Westinghouse was ready to produce 10,000 to 20,000 diodes a month. The total production was sold to the P.T.T. and the CNET (Centre National d'Etudes des Télécommunications) whose engineers mounted the repeaters in telephone lines, and the amplifiers in radio sets and transmitters. In June 1949, they conducted a demonstration in the presence of French government officials who congratulated them and alerted the press.

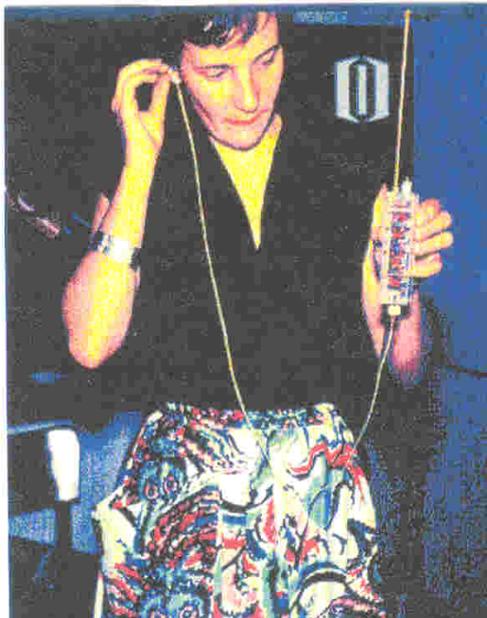


(Courtesy of Deutsches Museum)

Shortly after the press conference the French government decided to concentrate all its efforts on the development and production of atomic power, and to let private companies produce and supply semiconductors. Mataré returned to Germany and founded Intermetall in Düsseldorf. Through a French lawyer he came into contact with Jakob Michael, the owner of New England Industries, a company established in Wall Street. Before the war, Mr. Michael owned a very popular chain of department stores Defaka - Deutsches Familienkaufhaus. Being Jewish, he had emigrated to the United States. After the war he recovered whatever was left of his property. Several stores had been reopened and profits were substantial. But exchange controls prevented him from converting his German marks into dollars. He thought up a scheme that would enable him to transfer his assets, and was very much interested in buying German products he could sell in the United States. He supplied the funds that enabled Mataré to set up production of diodes and transistors. Within a very short time, the company started producing and selling successfully.

The transistor presented Intermetall's team of scientists with challenges and opportunities hitherto unknown. Some of the engineers Mataré had brought with him from France were very clever. Within a few months, production started and Intermetall was the first company in the world to sell diodes and transistors. They soon started dreaming up applications. One them was a transistor radio. The transistor was a new technological marvel able to reduce the radio from a bulky lump of furniture to a hand-held, pocket-sized gadget. It required little power and did not burn out, promising reliability and longevity

In August 1953, at the Düsseldorf Radio Fair, a young lady wearing a black sweater and a multicolored flowery skirt demonstrated to the public a tiny battery-operated transistor radio. The housing was made of transparent plexiglas; the sound was amplified by four transistors and transmitted through an earphone. It was a prototype developed by Intermetall, the small company founded the previous year by Herbert Mataré.



In 1953, he emigrated to the United States. Dr. Mataré is currently a consultant for Pyron Inc., a solar energy company based in La Jolla, Calif. Pyron holds the world record in lens-surface per ground-surface, and co-operates with BOEING-

Spectrolab to achieve the world record in the lowest solar-electricity price. At 92, after being a co-inventor of the transistor, Dr. Mataré works on the technology that will provide the electricity for the 21<sup>st</sup> century.

He has recently published two books, which constitute, in fact, his memoirs: *Erlebnisse eines deutschen Physikers und Ingenieurs von 1912 bis zum Ende des Jahrhunderts* and *Von der Radartechnik zur modernen Kommunikationstechnik*.

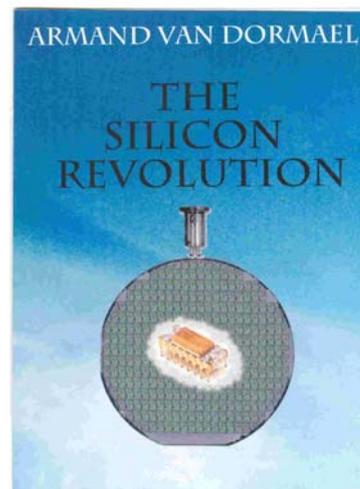
In a 13-page unpublished paper, *The lesser known History of the Crystal Amplifier*, Dr. Mataré relates how he came upon the idea of using silicon and germanium as amplifiers. The paper will be published on my Home Page [www.avandormael.net](http://www.avandormael.net), together with about 150 pages of archives and various types of documents. Historians and electronics scientists who are interested in investigating the subject more thoroughly will be able to examine all the papers I have collected for *The Silicon Revolution* which I am in the process of finishing. This will put them in direct contact with the past and provide new scientific insights into the origins of microelectronics.

Some of the originals have been hidden away for more than half a century in various institutions in France and Germany. It took patience, perseverance to locate them, and a brief and fortuitous encounter with the archivist of the Deutsches Museum in Munich to unravel the ephemeral history of the "French" transistor. The full story will be told in my book.

#### PROLOGUE

- 1 FROM ABACUS TO MICROPROCESSOR
- 2 THE "FRENCH" TRANSISTOR
- 3 THE STILLBORN PIONEERS
- 4 THE AMERICAN CHALLENGE
- 5 EUROPEAN TECHNOLOGY POLICY
- 6 SINS OF COMMISSION
- 7 EPITAPH FOR THE CHAMPIONS
- 8 SILICON VALLEY
- 9 PRESENT AT THE CREATION
- 10 THE BEST AND THE BRIGHTEST
- 11 WINTEL POWER
- 12 SILICON ASIA

#### EPILOGUE



It all started in 1997, when I decided to buy a new computer. To my surprise I found that brands such as Philips, Bull, Olivetti, ICL and Siemens which had been prominent for years, had disappeared from the shop windows. The computers selling in Europe were branded Compaq, Dell, IBM, Apple, Packard Bell, Fujitsu-Siemens, Gateway, Toshiba.

I wondered why the European computer industry had vanished and was forced to withdraw from the high-tech manufacturing frontier. Why did European countries lack the ferment, the emulation and the start-up culture that turned California into the center of the world's prime industry? What set of circumstances transformed poor and backward Asian countries, seemingly doomed to stagnation, into the factory floor of global electronics production?

The history of computing has been abundantly documented. I read a number of recently published books and articles, but did not find an answer to my questions and

decided to find out by myself. Unacquainted with the history of electronics, I had to start from scratch. I covered much unexplored territory and learned a great deal in those seven years.

The silicon revolution, like any industrial development, emerged from the chance combination of three elements: scientists with their invention, entrepreneurs to market it, and investors willing to risk their money. *The Silicon Revolution* provides in broad strokes an historical perspective and an overview of the computer industry in the United States, Europe and Asia, and an explanation of what made the difference between success and failure.

The evolution of the American, European and Asian micro-electronics industries bears the stamp of the dominant values that make people and policymakers think and act within established patterns. American entrepreneurs have an astounding track record of turning scientific inventions - both home-grown and borrowed - into new and useful products. Today, largely because of its excellence in microelectronics, the United States, driven by the inventiveness, the marketing and management, the brainpower and the relentless drive of its high-powered entrepreneurs, dominates the global economy.

Start-ups relentlessly create the new products and the new enterprises that provide massive new employment and wealth. America's social contract is based on self-determination. By and large, Americans consider themselves autonomous individuals, quite capable of taking care of themselves and eager to do so without much government interference.

An industry that exploded 20 years ago has generated a winner-takes-all economy. Global competition has changed in its nature and its extent. It is impossible to comprehend the essence of the electronics industry without forming an overall view of how it works globally. The United States holds a commanding lead in most areas that are crucial to the information society. Successful and innovative start-ups had the skills to create proprietary standards that allowed them to capture monopoly or semi-monopoly profits. Their comparative advantage rests on the ability to upgrade their products.

The seminal moment of the personal computer is truly astounding. The silicon revolution is the outgrowth of the creativity of exceptional individuals, computer fanatics, garage tinkers, innovative entrepreneurs and their financial backers.

In January 1975, the cover of *Popular Electronics* featured the picture of a computer with a caption reading: "World's first minicomputer kit to rival commercial models - the Altair 8800." An article promoted the Altair as "a full-blown computer whose performance competes with current commercial minicomputers." The machine sold for \$395 as a kit and \$495 assembled. Putting it together was said to be made easy with the aid of a manual. Free consultation service was available. The ad had been placed by a small company located in Albuquerque, New Mexico, whose owner had fallen onto hard times and was heavily in debt to his bank. Determined to make it all or nothing, he decided on a succeed-or-bust marketing operation. He put together a small personal computer based on Intel's 4004 transistor.

The Altair inaugurated a mass learning experience in digital electronics. Thousands of computer fans bought a kit. Inveterate hobbyists hungered for a computer they could play with, explore its inner complexity, experiment and hook it up to other electronic gadgets. The Altair's shortcomings forced the hobbyists to be creative. They became fascinated by their capability of putting it together and correcting its deficiencies.

Soon, computer hobbyists began to assemble their own machines using off-the-shelf parts and making an improvement here and there. Some emerged as computer or component manufacturers in their own right. The successful ones developed a niche market. When Steve Jobs brought out Apple, the desktop made it affordable to connect it to powerful computing devices.

In 1982, Compaq started selling an IBM clone. When IBM reluctantly and belatedly decided to enter the PC market using Intel microprocessors and Bill Gates' software, it set the standard for the industry.

Steve Jobs, Bill Gates, Michael Dell, Marc Andreessen and their competitors sometimes operated at the edge of disaster. As their business grew, most of them had to hire a manager who knew how to run their company. They are the wunderkinder of the American way of life. Driven by the urge to conquer the world, topple industry giants and overrun existing business practice, they acted as a disruptive force by putting a new idea into use. Risk and uncertainty were their constant companions. They owed nothing to government attention. They focused on a vision. Their ideas were simple, the execution extremely complex. Except for Andreessen, they had little scientific or engineering background. None of them had any money to start with. They turned Silicon Valley into the dream factory where new ideas constantly germinate. The silicon revolution is a textbook example of "creative destruction" as the heart of vibrant capitalism, incessantly revolutionizing the economic structure from within, incessantly destroying the old one while creating a new one.

Asian governments refrain from intervening in the economy and let the entrepreneurs run the show. They understand that their countries will thrive if entrepreneurial spirits are given full rein. They see to it that the infrastructures, the educational system and favorable tax rates give the country the greatest possible comparative advantage. Within a few years, they have created a huge pool of engineering graduates and a highly educated, skilled, motivated, reliable, disciplined and efficient workforce.

The Japanese led the way: they bought, adapted or pirated American technology. Master copycats and disciplined workers, efficient at improving whatever they imitated, they constantly upgraded their products and their industrial capabilities. Capitalism has unleashed the extraordinary vitality of the Chinese people and transformed their immense continent into the fastest-growing powerhouse of the knowledge-based economy.

The global electronics industry is a very complex network of R&D and manufacturing, with a high degree of interpenetration. Investment capital flows to areas where it can be used most effectively. Companies seek out the least expensive areas, particularly for the labor-intensive processes. The onward march of globalization deprives governments of their traditional instruments of economic power.

One of the great mishaps in economic history is the débâcle of the European computer industry. The failure brings up a vast number of questions that have not been addressed. Europe is the birthplace of the semiconductor revolution, but within two decades the combination of American technological prowess and Asian productivity has transformed the global industrial landscape. The synergy between the technological revolution and global capitalism has reshaped the foundations of the world economy. Europe has been compelled to cede the IT market - and the jobs - to foreign competitors and with it the manufacturing expertise and technical and scientific competence.

The theoretical and practical foundations of the technology were laid in Europe: the program-controlled electromechanical computer, the commercial computer, the transistor, the desktop computer and the www. The integrated circuit and the microprocessor are products of the brain drain. They germinated in the minds of European scientists working for American companies: Jean Hoerni and Federico Faggin.

In the 1960s, several American companies started selling mainframes in Europe. IBM had risen to worldwide leadership through superior technology, management and marketing. The company was able to maintain its dominance by constant innovation. A number of European electronics companies set up production of computers, but they were unable to respond to IBM's price-performance, its software availability and service and support levels.

The governments became alarmed by the technology gap which threatened to make essential segments of their electronics industry uncompetitive. Computer manufacturers, unable to hold their own in the marketplace beseeched the political class for financial help and protection from foreign competitors, claiming that the US and the Japanese governments were providing huge subsidies to their electronics industry by financing R&D. Instead of taking up the challenge, they retreated. Governments granted huge amounts of public money to their "national champions" through subsidies, defense and state contracts, in addition to shielding them from competition through tariffs, anti-dumping duties and 'voluntary' export restraints.

Guided by socio-political motives rather than sound business judgment, they featherbedded companies which felt comfortable selling overpriced machines in their local markets. When it became evident that the national-champion policy failed, the governments turned to the European commission.

In the early 1980s, the commission took over the central role in the promotion of the "European champions" by coordinating and financing co-operative R&D programs. This created a bureaucratic complex run by the commission and the industry. European technology policy was a costly and abject failure. The advent of the personal computer took the European industry and the commission by surprise. When the 'Compaq shock' served notice that there were new players in the game, it took quite some time to realize that American start-ups were producing microcomputers based on open standards and were obsoleting mainframes, the foundation of IBM's power.

Ever since, Europe has declined into second-class without noticing it and without admitting the declension. The causes are diverse and must be analyzed separately. Europe is an inhospitable place for entrepreneurs. A major obstacle to industrial competitiveness comes from political interventionism, from the regulatory burdens imposed by governments and the commission, and from the excessive costs of production and taxation.

The global economy is increasingly interlinked: labor costs, manufacturing skill and entrepreneurship determine where products are manufactured. Money moves freely around the world; jobs do not. The people who decide about new investments conform to the realities of global capitalism. With the exception of Ireland and Scotland where American and Asian companies have set up assembly operations, the computer industry has vanished from European factory floors. The dream of national or European champions has evaporated. So has the view that governments can rescue high-tech companies against the harsh logic of the global marketplace.

Europe is headed toward a critical collision with globalization. The electronics technology, crucial to any economy, has its home base in the United States and Asia.

Technological innovation is the major determining factor for long-term economic growth. Nations unable to develop or attract and nurture new industries will be left behind.

Hampered by the rules and restrictions that bind them, business leaders are hardly visible in Europe, except when their misdeeds hit the headlines. Entrepreneurs do not turn into folk heroes for having created a successful business and new jobs. Hence, Europe hardly has any. Europe is not a magnet for foreign investment. The short-lived European electronics industry has suffered a number of indignities from which it will not recover. There is no indication that history will give the European economy a second chance.

It may come as a surprise that France is not only the birthplace of the transistor but also of the Intel-powered desktop. In 1973, two years before the debut of the Altair, a 'Français d'Indochine', André Thi Truong, was on a visit to the United States. He learned about Intel's 8008 microprocessor and decided to buy some. He set up a company near Paris, and with a small team of engineers he designed and built an automatic calculating machine which he called Micral. It was rugged, well designed and easy to use. He demonstrated it at the National Computer Conference in Chicago. The American magazine *Byte* named it a "microcomputer". Priced \$1,750, about 2,000 units were sold in France within two years, mainly to banks and industry. Because of its limitations and because Truong lacked financial expertise and marketing skills, the venture failed.

The history of computing inevitably leads to the transistor. The invention of the transistor by William Shockley, Walter Brattain and John Bardeen has been admirably described in *Crystal Fire*. The genesis of the transistor is one of the great epics of modern physics and stands high in the history of human knowledge. Yet, very few academic historians have been interested in exploring the development of what is considered the most important invention of the 20th. century. One of the reasons may be that, for the nonscientist, the technical jargon barrier is insuperable. I have been lucky to write the history of the "French" transistor by translating and copying Dr. Mataré's papers, without really understanding what he means.

While browsing for information about the development of semiconductors, I came across a small book, *Der Transistor* by H. Hillmer. The author summarizes the biography of "forgotten" German scientists who developed the theoretical foundations of the technology but whose breakthroughs have not been tied in with the prehistory of the transistor. For several generations some had extracted silicon and germanium from nature; others had formulated theories about the possibility of replacing vacuum tubes by semiconductors, but they did not have the expertise to produce a functional device.

## PREHISTORY OF THE TRANSISTOR

The transistor was an extraordinary technological breakthrough and arguably the most complex man-made creation in history. Its genesis is one of the great epics of modern physics and stands high in the history of human knowledge. Groundbreaking insights by generations of scientists resulted in the theoretical construct and ultimately in the production of semiconductor material and from there to the transistor. The prehistory of the transistor covers 124 years.



In 1824, Jakob Berzelius, the most famous and influential chemist of the day, isolated an element which he called silicium. A young German chemist, Friedrich Wöhler (1800-1882), went to Stockholm to work with him. During his lifetime he established the basic principles of modern science and is considered the founder of organic chemistry. He discovered it was possible to obtain silicon in crystals.



**Karl Ferdinand Braun (1850-1918)** discovered asymmetric conduction in metal sulfide crystals. He used the rectifying properties of the galena crystal to create the cat's whisker diode. In fact, he discovered the point-contact rectifier effect and realized the first semiconductor device. The result was a 'rectifying diode', which lets current through one way, but hinders flow the other way. Braun's groundbreaking discovery opened the door to the field of semiconductor microelectronics. But the potential and the practical importance of his experiments were not understood. In

1897, he built the first cathode-ray oscilloscope, the Braun tube. In 1909, he shared the Nobel Prize in Physics with Marconi for achievements in wireless telegraphy.



In 1885, **Clemens Alexander Winkler (1838-1904)** examined a silver ore of unusual appearance. He observed that the sum of all the ingredients did not add up to the original quantity. After several weeks of painstaking search, he came to the conclusion that argyrodite contained an unknown element. He could not identify it, but discovered that it fitted the description of the hypothetical mineral whose existence Dmitri Mendeleev had predicted and for which he had left a space in his *Periodic Law of the Chemical Elements*. Winkler decided to name it germanium, in tribute to his homeland.



**Karl Bädeker (1881-1918)** lifted the standards of research in the field of semiconductors to a higher level. He made the first systematic and highly sophisticated scientific study of the basic chemical and physical properties of semiconductors. He used the best chemical and physical techniques available at the period to produce thin films of pure metals on glass or mica. These were then transformed into compounds, such as oxides, sulfides, and halides by exposure to appropriate vapors. The methods he used were highly sophisticated for the time. They represented a significant step forward in gaining control of chemical composition while working with a simple physical configuration.

Bädeker lifted the standards of research in the field of semiconductors to an unprecedented level. He demonstrated that, apart from surface effects of the type leading to rectification, semiconductors obey Ohm's law intrinsically. He was called into service in August of 1914, at the outbreak of World War I, and died in battle the first week at the age of 37.

In 1906, the vacuum tube was developed almost simultaneously, in Germany by Robert von Lieben, and in the United States by Lee De Forest. A stream of electrons

flowing from the cathode to the anode could be controlled by means of the voltage at a third electrode, the grid. The vacuum tube became for decades an essential component in the development of telephony and radio. But the vacuum tube was bulky, unreliable, and required frequent replacement.



In 1926, Julius Edgar Lilienfeld (1882-1963) applied for a patent related to a “method of controlling the flow of an electric current in an electrically conducting medium of minute thickness, which comprises subjecting the same to an electrostatic influence to impede the flow of said current by maintaining at an intermediate point in proximity thereto a potential in excess of the particular potential prevailing at that point.” In 1928, he filed a claim relative to “An amplifier for electric currents, comprising two outer layers and an intermediate layer in intimate contact therewith, the layers being of material such that asymmetric couples are formed by the respective outer layers with the opposite faces of the intermediate layers and being interconnected in part thereby, means to apply potentials of same sign to the outer layers, and means to apply a potential of the opposite sign to the intermediate layer.” The patents correctly outlined the field-effect principles, but he could not have built a device, because the required high-quality semiconductor materials were not available.



In 1913, Walter Schottky (1886-1976) formulated the basic law relating current in a valve to the applied voltage, or what is known as the "three-halves law". Between 1915 and 1919, at Siemens' industrial research laboratories in Berlin, he pursued his investigations in electronic valves resulting in the invention of the screen-grid tube and the tetrode, the first multigrid vacuum tube.

In 1918, in his classic paper on noise in valve amplifiers, he reached the conclusion that there are two sources of noise. The first occurs in the input circuit and results from the random motion of charge caused by the thermal motion of the molecules in the conductors. The second source of noise is caused by the randomness of the emission from the cathode and the randomness of the velocity of the emitted electrons. His findings led to better valves and benefited the next period of his career, the semiconductors.

His work with semiconductors is considered the most important part of his career. Throughout the 1920s, he gathered material which he used for his book *Thermodynamik* where he formulated the thermodynamic theory of purified solids and revealed the existence of electron “holes” in the valence-band structure of semiconductors. The material had become pure enough for controlled applications. In 1935 he noticed that a vacancy in a crystal lattice results when an ion from that site is displaced to the crystal's surface, a type of lattice vacancy now known as the Schottky defect.

In 1938 he formulated a theory explaining the rectifying behaviour of a metal-semiconductor contact as dependent on a barrier layer at the surface of contact between the two materials. The metal semiconductor diodes later built on the basis of this theory are called the Schottky diodes.

He also discovered that the current emitted from the metal cathode into the vacuum depends on the metal's work function, and that this function was lowered from its normal value by the presence of image forces and by the electric field at the cathode. This effect became known as the Schottky effect. Schottky prefigured developments and made inventions that revolutionized the field of electronics. The word "Schottky" has been transformed from a name into a technical term associated with the construction of a wide range of electronic components.



**Oskar Heil (1908-1994)** developed the theory of the field-effect semiconductor and in 1934 he applied for a German patent for the *“Anordnung zur Steuerung von Strömen.”* When the excessive thoroughness and meticulousness of the German patent office delayed the examination he translated the application and filed for a patent in Britain claiming the invention of *“An electrical amplifier or other control arrangement or device wherein one or more thin layers of semi-conductor traversed by current is or are varied in resistance in accordance with control voltage applied to one or more control electrodes arranged close to and insulated from*

*said semi-conductor layer or layers so as to be in electrostatic association therewith.”* The patent was issued within nine months. It refers to the p-n junction principle. Both ends of a thin semiconductor chip are covered with a metal strip and serve as source and drain contacts. A third electrode serves to regulate the conductivity of the semiconductor material. He suggested tellurium or vanadium pentoxide. There is no evidence that Heil actually tried to build a functioning device based on this concept. Practical implementation was impossible because the materials required did not yet exist. In 1935, together with his wife, Agnessa Arsenjeva, he published a groundbreaking theoretical article *“Über eine neue Methode zur Erzeugung kurzer ungedämpfter elektromagnetischer Wellen grosser Intensität.”* For several years he was absorbed by an intensive research program covering the human ear and the listening and vocal apparatus of small animals which are able to produce loud sounds compared to their size. This led to his discovery of the principle on which the legendary Air Velocity Transformer is based. By applying this principle to the design of a loudspeaker diaphragm, he achieved a revolutionary breakthrough and solved the fundamental problems of diaphragm mass, inertia and self resonance. He spent some time in Britain working at Standard Telephone and Cables where he developed the Heil tube which is the forerunner of the klystron, the first vacuum tube able to overcome transit-time effects in triodes and tetrodes. Klystrons are the most efficient of linear beam microwave tubes and are capable of the highest peak and average powers. Heil returned to Germany the day before Britain declared war. For several years he worked at Standard Elektrik Lorenz in Berlin. After the war he was brought to the US by the military and was employed at Wright Patterson Air Force Base.



**Robert Wichard Pohl (1884-1976)** investigated the electrical and optical properties of highly purified alkali halide crystals containing a stoichiometric excess of alkali metal atoms. He foresaw the possibility of controlling electric current in solid-state crystals through a grid. His first successful experiments in solid-state repeaters were conducted with the help of his assistant Rudolf Hilsch. In 1933, Pohl made the visionary forecast that vacuum tubes would one day be replaced by semiconductors in

radio receivers, provided the movement of the electrons could be controlled.

In 1938, Pohl and Hilsch published a paper called: "*Versuche zur Steuerung von Elektronenströmen mit einem Dreielektronenkristall und Model einer Sperrschicht.*" It was a description of a three-electrode crystal used as an amplifier. They used a metal bar across a crystal of potassium bromide. The conductance was ionic and the steering electrode had a relatively small influence on the current flow, the value of  $dI/dU$  being only 15 for the points between 100 volts and 150 volts at the anode. In addition, ionic conduction did not allow for high-frequency amplification and transconductances were low. The device modeled the vacuum tube, but the materials properties were not well understood. This, however, was probably the first demonstration of a solid state amplifier. All other tests on semiconductor layers to influence carrier flow by applied fields had been unsuccessful because of the negligible field influence (penetration) due to the shielding surface charges. The rectification at a semiconductor boundary is analogous to that obtained in a vacuum tube diode. In a vacuum tube, current flows more easily in one direction than in the other. This occurs when the cathode with the higher work function is made positive with respect to the other cathode. This is analogous to the n-type semi-conductor in contact with a metal which has a small work function. A p-type semiconductor in contact with a high work function metal is analogous to a reversal in the sign of rectification. Here the charge carriers are holes. This was however a slow process, not comparable with electron flow in a vacuum, due to the strong lattice interference. The imitation of the vacuum-tube worked with a grid structure built into the KBr-crystal. They measured the amplification of a signal applied to the grid-structure and base. As inferred from the ionic low mobility, the frequency response was very low. It made the device unusable for practical purposes. However, this was the first solid state amplifier or three-electrode-crystal. The experiment foreshadowed the possibility of a new technology as a replacement of the vacuum tube and was an important milestone on the way to the transistor.

The ultimate purpose of this fundamental research in the 1920s and 1930s was the steering of electric current. Germany had a long tradition of technical brilliance in engineering and in basic research. The interdisciplinary research, the co-operation between theoretical and experimental physicists, mathematical physicists and chemists contributed immensely to the growth of solid-state physics and semiconductor technology during the period 1930-1945. The term '*Festkörperphysik*' was commonly used before the war in scientific literature. Until 1938, solid-state research remained essentially academic. It was conducted to advance fundamental knowledge, with no thought of practical use, until the scientific community began to realize that semiconductors might have a huge industrial potential as repeaters capable of replacing the vacuum tube.

The realization of a novel device such as the transistor requires a specific material, a specific theory and specific expertise to apply the theory to the material. Berzelius and Winkler provided the elemental semiconductors; Wöhler, Braun, Bädeker, Lilienfeld, Heil, Schottky and Pohl were the major contributors to the theory. Technical innovation requires a certain period of gestation. Breakthroughs occur when research is driven by an urgent need - in this case the demand for radar receivers in the ultra-high-frequency range. Mataré and Welker developed the expertise to produce a functional transistor.

The book also mentioned that between 1946 and 1951, Heinrich Welker and Herbert Mataré had produced diodes and transistors in France, for account of the French government. Welker had been for several years in charge of Siemens' research in semiconductor physics. I contacted Siemens and was told that his papers are deposited at the Deutsches Museum in Munich. Two days of looking into his correspondence revealed that he had been working at the frontier of crystal-growing technology and had exchanged ideas and information with Heisenberg, Schottky and other scientists.

Mataré's papers are also preserved, but the archivist told me that personal documents are not accessible during the lifetime of the scientist. As I expressed disappointment and was leaving the room, he called me back and gave me his address in Malibu, California. I sent Dr. Mataré a copy of Welker's invitation to the Paris press conference. Two weeks later, when I found in my mailbox a long letter explaining how he had developed the first transistor, it was one of the great thrills of my life.

Based on information provided by Dr. Mataré, I have tried to bring to life an episode of the electronics history that would probably have been lost forever. Writing the story of the "transistron" and explaining the intricacies, the issues and the complex theoretical phenomena, using an arcane technical jargon is not without risk. To make it stand up to scrutiny, I asked Dr. Mataré to review the drafts.

The journey was worth taking. My reward has been to personally meet the scientist who ushered in the digital age and to see to it that he finally gets his due. I am grateful to Rik Nebeker for giving me a chance to make a contribution to the preservation and promotion of the legacy of electrical engineering and computing. For more than half a century, the "French" transistor was a non-event. It is now history.

Over a period of more than two years, Dr. Mataré sent me a number of letters. They constitute a major contribution to the history of electronics. Insofar as they should be of use to researchers wishing to explore the subject, the most instructive will be posted on my Home Page: [www.avandormael.net](http://www.avandormael.net).

Prof. Dr. sc. phys., Dr. Ing. **Herbert F. Mataré**  
DIRECTOR **International Solid State Electronics Consultants (ISSEC)**

Malibu, 3/7/02

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Dear Sir:

Thanks for your letter with the funny Thomas invitation which reached me today, a few days before my next flight to Paris and back to my family and office in Germany, where I spend the summer months before returning here in autumn.

You have touched on an interesting point, when you wrote that the history of the transistor is "unzugänglich". That is, why I submitted my papers and an early transistor model to the archives in Munich. - Thanks also for transmitting Dr. Füssl's greetings!

During the war, my colleagues and I, working on the semiconductor-diodes for Radar-mixer stages, were well aware of those paper-patents by O. Heil and J.G. Lilienfeld, who developed semiconductor amplifier schemes before the war. But these and also the crystal amplifier published by Hilsch and Pohl could not solve the problem, in the field effect cases due to the surface states and in the case of the ionic crystal due to the high time constants. --(as to the surface states, they were later, after the war, discussed in a famous paper by Bardeen in Phys. Rev.) My colleague Welker had also applied for a field effect device, around 1945 and done some testing but could not get any results of amplification nor did Shockley at Bell Labs. Welker discussed this problem with me in Paris and seemed rather disappointed, saying "I have done so many tests but could never get any transconductance". That was in the beginning of our build-up of the diode production in Paris 1946/47. - My experience started during the war, when I had to equalize detector characteristics in an effort to make duodiodes i.e. crystals with two whiskers which had to yield equal characteristics. This double diode device was the soul of the radar-mixer stage for heterodyne reception of cm-waves to eliminate as much as possible the local oscillator noise. --(see my book on "Empfangsprobleme im Ultrahochfrequenzgebiet" Oldenbourg, München 1951) In the "Verlagerung" of the Telefunken Labs to Silesia (because of the bomb raids on Berlin) I found during some tests that I got interference of one characteristic on the other, but I had no time to study this further because of production pressure to deliver the duodiodes and also due to the abandoning of the lab 1944., when the Soviet Army occupied Silesia. - I have described this in my recent Autobiography (in "Der Fernmeldeingenieur", Verlag für Wissenschaft und Leben, G. Heidecker GmbH, Postf. 3566, 91023 Erlangen, April/Mai 2001) In Paris I started again the duodiode production for microwave mixer stages and, as in 1944, I found again strong barrier interference in some cases. That was in 1947, as the germanium-crystals which Welker produced in his Bridgman furnace were made at larger volume at my request. (better mass/surface ratio) --The improvement of the Germanium purity (desired for a better diode characteristic) brought about the possibility of defect-electron conduction and thus the transistor effect. - This was the same situation as at the Bell Labs in Murray-Hill, where Bardeen and Brattain also asked the crystal growers, like Dr. Teal, to grow purer crystals. They had the injection effect in december of 1947 while I had amplification with duodiodes beginning 1948. - I have discussed this situation with

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Dr. Brattain and Dr. Teal in 1950 at the London conference and later on with Prof. Lark Horovitz at Purdue University. - He told me, that they had carefully watched the German work during the war years. - At the beginning Welker considered this as a spurious field effect and did not show much interest until I had clear high-frequency amplification. Only after the news from the US came over to Paris, that some device called the transistor had been found, showed the director of the PTT and the Minister Thomas interest and coined the device "Le Transistron" - During this time Dr. Welker was very active to pursue his amphoteric conduction theory of superconductivity which he had started already during his years as assistant to Sommerfeld in Munich. In fact, we often discussed this theory and Welker published papers in German Physics Journals, like Zschr. f. Naturforschung. He recognised our discussions in these papers. Even after 1950, at Siemens, he published on superconductivity and was near to the Bardeen-Cooper-Schrieffer-theory of electron-phonon coupling with his theory of hole-electron pairs. - That was at the time when he had started the Siemens - work on III-V-compounds. -

We produced higher frequency transistors than the Bell Labs. But after 1950, when we left Westinghouse, interest in Paris concentrated on atomic energy and the electronics sector underwent many fatal transformations. (see e.g. Bull) - The story of the transistor has been described by Dr. Kai Handel in his dissertation "Anfänge der Halbleiterforschung und Entwicklung" - Aachen 1999. (Institut für die Geschichte der Technik, Prof. Dr. Kaiser) - Also Prof. Hillmer has given a short history in: "Der Fernmeldingenieur" as above 1/00-2/00-3/00. - On request I have just sent in a manuscript describing my reminiscences from the first radar-detector to the transistor, also in "Der Fernmeldeingenieur" -

I hope that these remarks will help you in your research. It would be very valuable if you would publish a more coherent story about this interesting development, so that also less technical readers would find the text interesting, which is mostly not the case when a scientist or specialist in the field describes his work. The last address of Dr. Handel was: Institut f. Wissenschafts und Technik-Geschichte, Techn. Universität und Bergakademie Freiberg 09596, Tel. 03731-39-2835 Fax 03731-39-2832. But I think, you can get the dissertation also from Prof. Kaiser in Aachen.

INTERMETALL was started in 1951/52 in Düsseldorf. I had hoped that, after the transistor production had started, I would be able to continue the research on III-V-compound semiconductors there but England Industries in New York requested sale of the company and concentration on production only. - So I searched for a new Investor and found the Clevite Corporation which had also bought the Shockley Transistor Corp. in 1952. Later, when my colleague Dr. Seiler took over, ITT was the investor. - Finally in 1998 a Swiss group took over.

Yours sincerely



(Herbert F. Mataré)

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28.09.2003

Dear Mr. Van Dormael:

Congratulations to your membership of the AAAS. Now you may be able to publish a summary of your book in SCIENCE.

To your questions concerning Aulnay sous Bois: Unfortunately I do not have any pictures of our small lab in Paris. To describe it: Dr. Welker had put up his HF-generator in the basement. It served to heat the Quartz tube in which was mounted the graphite holder with the germanium ingot. We had no equipment to outgas the graphite, as we had in Düsseldorf. We did not have a Czochalski puller to make monocrystals, as we had established in Düsseldorf.-So, Welker tried to clean the graphite after each crystallization run by heating the empty boat under hydrogen.-The problem was that the so called "pure" hydrogen delivered to us was irregularly clean i.e. it contained varying amounts of water. We had no such problems in Düsseldorf with the hydrogen delivered to us.

Also, the generator was not working well and I had to redesign the coupling coil, before Welker could get sufficient heating to melt his ingot.-Our diode production began to work reproducibly only after we got germanium from Otavi Minen Co at the end of 1947. But the crystals were still overdoped and I asked Welker to change his boat design so that we got larger crystals. I found that the higher bulk-to-surface ratio improved the crystal structure and that we had more monocrystalline areas. This facilitated the search for equal characteristics of double diodes for microwave mixers. At the same time I found out that I got interference from one side (barrier) on the other, as I had seen already during my earlier tests in Leubus (Silesia) in 1944.

I had to arrange my measuring equipment myself, with the help of one mechanic, while we had several electronic specialists helping in Düsseldorf.- I found out that crystals with grain boundaries offered barrier layer interference at much wider distances than was possible on monocrystalline areas. (that was the birth of the "grain boundary transistor", a precursor of the nanostructure devices) I published this first in Düsseldorf.

In Paris our diode and transistor-production was based on the ceramic holder design. (you have this picture on the same photo as the first transistor mount in plastic from the Deutschen Museum)-The second floor of the Aulnay building was full of measurement equipment for diode- and transistor characteristics. In Paris I had two technicians to build such equipment which was not purchasable. In Düsseldorf I was able to install a whole group for equipment building in a separate unit. The third floor in Aulnay allowed for just one test room and two small living areas for Welker and myself. Now to the PTT: As you may see from all those pictures by Marzin, Tomas, Sueur, Aisner etc. the same transistor was used in all applications there.

These were all transistors, produced in Aulnay -sous- Bois. I do not know of any germanium equipment or mounting and measuring equipment at the PTT labs which would have allowed the production of any of these devices.-Electronic engineers at the PTT or CNET labs were mounting amplifiers and repeaters for these devices but did not produce any of the diodes or transistors.

Westinghouse F & S delivered our production completely to the PTT labs.- In all the pictures of equipment built by CNET labs, which you sent me, you can see that the actual transistors within the equipments are the ceramic type which we produced.

Later on, when they acquired the Bell licence, Companies like Thompson CSF, Bulle etc. copied the Bell design with the metal can but had great problems with the stability.

Our transistors were so stable that Sueur was able to show Dr.Shockley that he could phone over such repeater stations. (beginning 1950)- The reference by Sueur to the US team was more to show that he was informed. He did not very much understand what was published. He was a typical paper pusher.- I do not know the detail published by Mr.Moreau. But the transistor was a French invention, insofar as it originated from double diode tests at Aulnay- sous- Bois i.e. in quite a different way than the surface test transistor at Bell Labs.

Anybody working at that time with high blocking voltage germanium diodes, would have found the barrier layer interference effect, especially when testing duodiodes as I did for the microwave mixers. It was all timed by the possibility to get the germanium pure enough. Our devices were relatively stable because I used grain boundaries to space the emitter-collector whiskers farther apart, which you cannot do on pure monocrystalline surfaces. The fixation at sub-micron distances is very difficult and you easily have a short circuit.- I was able to keep distances up to 100 microns.

The actual theory of all this was developed later on, when we understood that the grain boundary was actually a nanostructure with high conductivity. (see my book on "Defect Electronics", Wiley Interscience 1971).---Our transistors in Düsseldorf were also better performing at higher frequencies because we were able to use higher doped germanium crystals. I understand that this was the reason that Clevite Corp. was interested in acquiring the company, after they had tested our transistors.

As far as the production of transistors in Paris is concerned, I only recall that PTT and Thompson CSF and later on Bulle tried to produce according to the Bell licence, but that there were too many problems with the needed reproducibility. (recall our hydrogen purity problems in Paris)

In view of the great effort in France in the nuclear field, I think this sector of technology was not taken too serious and there was a certain feeling that one could always import these little devices. Nobody foresaw how important this whole electronics sector would become and that it finally would outgrow in dollar-value the nuclear industry.

I hope that this picture gives you some explanation as to what has happened in Aulnay-sous-Bois.  
I remain with best regards

Sincerely



(Herbert F.Mataré)

The life and times of a lawyer turned business executive before taking early retirement in order to paint, sculpt and write books on monetary economics and electronics history are of minor interest. But it has become customary for an author who wants to introduce himself to the cyberspace fraternity, to set up a Home Page so he can communicate with Internauts around the world and share information about the gleanings of his research.

My Home Page: [www.avandormael.net](http://www.avandormael.net) is under construction.

My e-mail is: [a.vandormael@skynet.be](mailto:a.vandormael@skynet.be)

## The Life and Times

Belgian parents living in rural areas and wanting their boys to have a broader education than provided by the local village school, used to send them for ten years as interns to a *collège* run by "fathers". This gave Flemish kids a chance to learn French, the language of the middle- and upper class. For many youngsters their formative years were an oppressive experience. Locked inside barracks-like buildings, cut off from the outside world, subjected to strict discipline by guardians rather than educators, they went through a routinely regulated and dreary life, with nothing worthwhile remembering.

At an age when young minds have the highest built-in capacity to develop innate intelligence and absorb information, the tuition focused on rote learning, with tedious conjugation and memorization of Greek vocabulary and Latin ablatives, thereby stifling innate curiosity, imagination and creativity. The natural sciences which stimulate children into finding out by themselves through observation and experimentation, and help them develop personal talents and sharpen the faculties for discovery, analysis, logical reasoning and precise thinking, were completely neglected. Books coming from the outside were confiscated. Bedtime was the best part of the day, when an earphone connected to a crystal radio brought music and voices from the outside world. Hidden under covers pulled over the head no supervisor would find out, not even the confessor who regularly cleansed the soul of secret sin. Youngsters emerged from these schools with a hidebound outlook and a mediocre knowledge baggage, but with a diploma that gave them access to the university, allowed them to chose a bourgeois career and - if successful - lead a privileged life.



It was my exceptional luck to have parents who let me spend summer vacations abroad, which opened windows on the world. At 17, a two-month stay in London, with language courses at the Polytechnic School in Regent street, were sufficient to acquire fluency in English. The following year, my parents who ran a sawmill sent me to Finland. Most of the timber they imported came from that country. From Vyborg to Leningrad was a short distance. Walking along the banks of the Neva river and the stately boulevards of this magnificent city, visiting the Winter and Summer Palaces was a fascinating discovery. I distinctly remember the pendulum swinging back and forth from the dome of the desacralized St. Isaac's cathedral. A six-week bicycle tour through Germany, lodging in well-organized youth hostels, was another interesting experience. German youth was trained to order and discipline. We left our bicycles

outside; nobody would have imagined they might be stolen. At the Nuremberg *Parteitag*, Hitler galvanized his followers with the prophecy of uniting all Germans into one nation. The militaristic character of the rally was impressive.



At the university, student life was fun-filled, summer vacations abroad were instructive and a doctor of laws degree very easy to obtain. An academic title naturally opened the door to the Bar and to initial training in lawyering. A world all by itself, the judiciary is there to sublimate conflict and maintain order. The law is the business of lawyers who are paid for what they say. The Rule of Law is maintained by conventional decorum and indeterminate situational ethics. Despite the ritualistic etiquette and an ambiance of solemnity enhanced by impressive robes, relics of another age intended to enhance the dignity of the profession and of the palaces of justice, the procedures involve comportments that would be considered morally unacceptable outside the courthouse. Rights and wrongs are chancy, the ends justify the means, truth is arbitrary and open to appeal. Finding no satisfaction in representing litigants, in out-lawyering opponents or associating with crooks and wastrels in exchange of a fee, I soon became disenchanted with the duplicity inherent in the adversary system of legal alchemy, dispute, argument, counterargument, semantics and deceptive tactics.



Unable to solve the problem of role morality in legal practice, I turned my back to the bench and decided to try my luck in business by joining a large American company. Here the ground rules, the standards of conduct and the ethical values are of a different order. Mutual trust between colleagues, between buyer and seller, openness, reliability and integrity are the only acceptable mode of behavior. I applied for a job at the Brussels buying office of Sears, Roebuck. Thanks to my unusual language proficiency, I was soon put in charge of the European operations, responsible for setting up and supervising buying offices in Frankfurt, London, Florence, Vienna, Paris, Barcelona and Bienne. The assignment was both challenging and rewarding. Sears, then the largest merchandising company in the world, purchased huge quantities and a wide variety of consumer goods, from toys, tools, cuckoo clocks and diamonds to motorcycles, watches, sweaters, tulip bulbs and porcelain. Visiting hundreds of factories - large and small - all over Europe during the *Wirtschaftswunder* years made me feel the pulse of an expanding economy. Serving as an intermediary between European industry and American consumers was a purposeful calling. But when steadily escalating manufacturing costs rendered the products of European industry uncompetitive, Sears' purchases gradually shifted to East Asia and the job became routine.

In 1975, I decided to start a new life, study history, economics and world affairs, write a few books, paint and sculpt. Having witnessed several monetary crises which I did not understand, I wanted to find out what laid behind them. The Bretton Woods monetary system had recently broken down. A considerable amount of literature was

devoted to its demise, but nobody explained how the IMF and the World Bank were born. Exploring the origins of the Bretton Woods system by drawing from the original documents seemed like an interesting challenge. It took three months of wading through the files of the National Archives, the Franklin D. Roosevelt Library, the Library of Congress and several other institutions, and to photocopy about 2,500 pages. It took another two years to analyze them, sort them out and integrate the documentation into a chronological narrative. The book, *Bretton Woods - Birth of a Monetary System*, was published in 1978. It came as a pleasant surprise when the Hoover Institution posted a broad selection on the web site of the IMF.

Bretton Woods, by Armand Van Dormael, is in my view also the best. The author has unusually penetrating insight into how things happen in the real world and into the psychology of his dramatis personae. He has mined deeply the masses of documentation. Above all, he has complete mastery of the issues, however abstrusely technical, that were under negotiation, and has a rare facility for explaining them clearly even to the uninitiated reader. – Brian Tew. *The Times Higher Education Supplement*

...a surprisingly absorbing book. The author has sifted to very good effect a huge pile of official documents... this is an intriguing story. - *The Economist*

...a most valuable and authoritative history:...of interest to international economists and economic historians. - *British Book News*

...well written and well documented... a fairly objective evaluation of opposing views... Van Dormael's study... provides perspective and insights to evaluate current debates about restructuring the international monetary system. - *Choice*

... the best consecutive account of the birth of the postwar monetary system. Paul Bareaud

... a thorough overview of the Bretton Woods Conference: - *Encyclopedia Britannica*

After finishing Bretton Woods, I took up sculpting for several years, while continuing to study history and economics. I may publish *The Making of Europe* or *The Third Way* on my web site, although they are merely variations on a theme. But Keynes' aphorisms about money are addictive. Money has a mystical quality; its history is fascinating. The most extraordinary and fecund monetary creation is the eurodollar, a deposit denominated in U.S. dollars but held in banks outside the United States. It developed by stealth during the cold war in the London and Paris subsidiaries of the Russian national bank as a stratagem by the Soviet government to protect its dollar holdings from the risk of blockage. Inventive bankers picked it up. Ever since, it serves the financial needs of the multinational corporations while defying any central bank's regulation about interest rates or reserve requirements. Because its value changes every day, European governments decided to set up a monetary system of exchange rates that would allow them to trade without being hampered by unpredictable currency fluctuations. In *The Power of Money* I tried to clarify and demystify the history of money and credit as well as the behind-the-scenes machinations for control of the global foreign exchange market. In 1997, I decided to buy a new computer. Seven years later, I am in the process of finishing *The Silicon Revolution*.



While at school, I had taken weekly sculpting lessons. Retirement provided the free time to take up this hobby again. It seemed like an interesting challenge to make a voyage through the history of sculpture by trying my hand at various forms of statuary. I learned to cast bronze, fire porcelain, arc-weld stainless steel and copper, and carve old oak. My career as a professional sculptor ended when the project of *The Silicon Revolution* took up all my time. A broad selection of my works will be shown on my Home Page.

