BY CARLOS ALBERTO FAZANO

# THE BIRTH OF SEMICONDUCTOR ELECTRONICS

In 1948, when the transistor was invented at the Bell Telephone Laboratories, the press treated the news almost indifferently. But the birth of this small semiconducting device was the beginning of a new era for mankind. The purpose of this article is to describe briefly the unfolding of the solid state era, from its beginning up to the development of the integrated circuit in 1965 — with emphasis on the evolution of solid state devices as detectors of radio waves.

## *The Earliest Detectors*

The story really begins around 1887, when the scientist Heinrich Hertz put the whole subject of electromagnetic radiation on a firm basis. In a series of classic experiments, he established that radio waves did exist and that they could be reflected, refracted and also polarized similar to light waves. But since these Hertzian radiations could not be perceived directly by human senses, it was necessary to provide some means for detecting them.

Early detectors utilized various physical principles, including:

(1) The cohesiveness of metal particles in the presence of radio waves, as in the coherer developed by Branley, Munk and Bose.
(2) The influence of magnetic fields, as in the electrodynamic or hysteresis detector. The development of this device is associated with Thompson, Fleming, Fessenden and Marconi.
(3) The heating effect of a current flowing in a wire, as in Fessenden's Barretter.

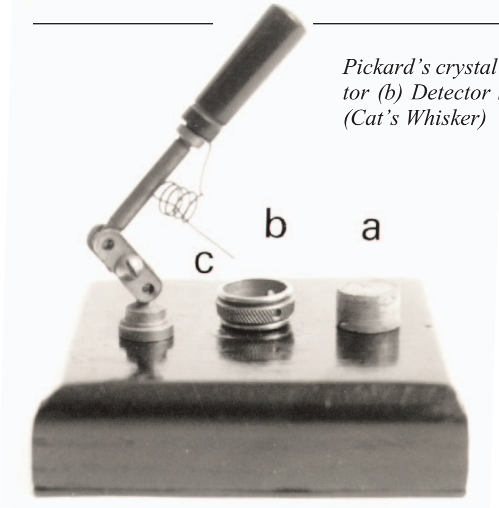
## *Crystal Detectors*

Of course these early detectors passed into obscurity after the discovery of the properties of crystals and other semiconducting materials.

In 1874, the german physicist Karl Ferdinand Braun discovered that certain minerals such as galena, lead sulphide, had the property of unidirectional conductivity. That is, they would allow the passage of alternating current passing in one direction but inhibit the return surge. His work


*English carborundum detector kit and sample of carborundum mineral.*

**AUTHOR'S ADDRESS: C. POSTAL 25, OSASCO, SP, BRASIL 06001-970**




*Pickard's crystal detector. (a) Mineral Detector (b) Detector Socket (c) Detector Contact (Cat's Whisker)*

established the rectifying properties of the contact of a metal wire on a selected mineral, creating the first metal-semiconducting junction.

In 1902 Greenleaf Whittier Pickard, building on the research work of Prof. Braun, developed the crystal detector for radio waves. Though Pickard's crystal detector had been manufactured since 1906, patent for his invention was granted only in 1908. About that time another experimenter, H.H.C. Dunwoody, began to use the detector in practical circuits. Dunwoody, while working for the U.S. Army, also invented the carborundum radio detector in 1906.

The sensitive and practical crystal detector was a leap forward in the detection of electromagnetic radiation. However, its use began to decline with the development of reliable thermionic devices.

## *The First Thermionic Devices*

The thermionic age began in 1879, with Edison's incandescent lamp experiments. Through studies to improve the quality of the lamp filament, he discovered that a current would flow, in a glowing lamp, from a metal plate inserted in the lamp to the positive filament terminal. This observation became known as the "Edison Effect."

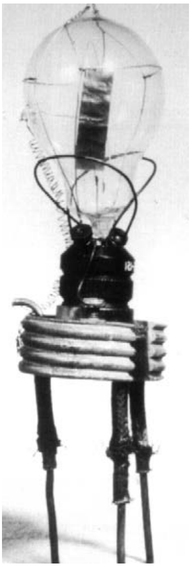
This discovery eventually led to the development of the "Fleming Valve," the first thermionic diode, in 1904. It was a practical rectifying device that was soon put to use as a radio detector. That discovery was followed a few years later (1906) by the three-electrode valve, or *Audion*, invented by Lee DeForest. DeForest's patent (granted 1907) was entitled: *Device for Amplifying Feeble Electric Current*. In this all-important paper, the inventor states that the Audion's output current is controlled by an electrode (the "third" electrode or "grid") that does not draw appreciable current itself.

In spite of the enormous potential of the Audion vacuum tube, its application was not immediate. Initially it was used as a wireless detector rather than an amplifier. This latter capability was first employed a few years later, based on the pioneering research work of such scientists and engineers as Fritz Lowestein, John Stone, and especially Dr. D. Arnold. By the early 1920s the vacuum tube had all but replaced the crystal detector for any serious radio applications.

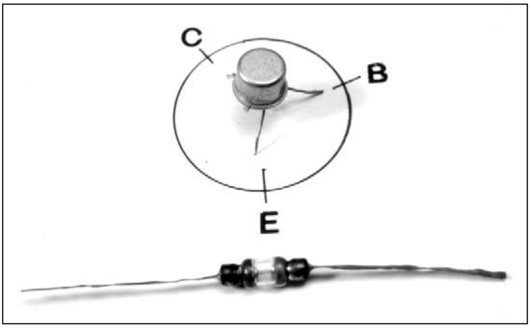
## *Semiconductor Diodes*

By the end of World War II, DeForest's Audion had evolved into a highly sophisticated device. However the engineers at Bell Laboratories, anticipating the mushrooming expansion of world-wide communications, were looking for amplifying and switching technology that (a) would be more reliable and less power hungry than the vacuum tube and (b) substitute for the slow electro-mechanical relays then being used for telephone system switching.

Through researches in the new field of solid state physics, scientists



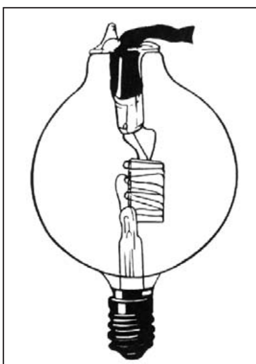
*The Fleming valve: first reliable thermionic device.*




*Bipolar transistor with emitter, base and collector leads labeled (top) and early germanium diode.*

finally developed a theory for the operation of a semiconductor rectifier. They discovered that certain crystalline materials, like germanium or silicon, though normally nonconductive, can be made to conduct electricity through the addition of small amounts of other substances, a process called doping. In the case of silicon, the substances are phosphorous or boron.

Phosphorous adds free electrons to the crystalline structure. Doping with phosphorous creates what is called "N-type" silicon. Boron adds "holes," or locations that can accept electrons. Doping with boron creates "P-type" silicon.



*Drawing of the original DeForest Audion.*

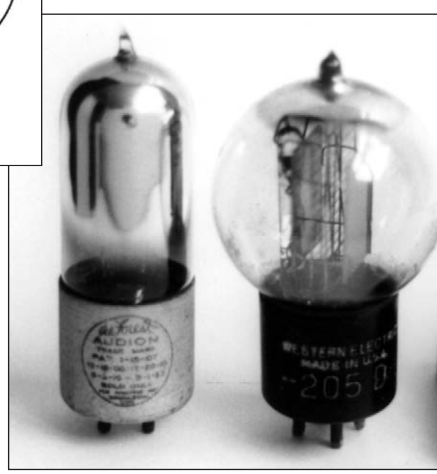
Electric current is a flow of electrons. In the case of the N-type material, the flow is made possible because every time a new electron is pumped into the material, a free electron leaves the material—making room for another new electron, etc. In the case of the P-type material, the current flow is established in a complementary manner. Instead of electrons, one can think of "holes," or "electron-need" sites, traveling through the material — with the holes accepting an electrons as they are pumped in.

When an attempt is made to pass current through a piece of P-type material and a piece of N-type material in contact with each other, the current will flow in only one direction across the boundary layer or "P-N junction." When polarity is in the current carrying direction, free electrons in the N material flow to the junction, cross it, and are accepted by "holes" in the P material. But when polarity is reversed, both the free electrons and the "holes" are forced away from the junction and there can be no current flow.

And so this diode, as it is called, acts as a rectifier, conducting only during the half of the a.c. cycle when polarity is favorable. Generally sealed inside a small glass or plastic tube, diodes are used in many electronic applications today.

## *The Transistor is Born*

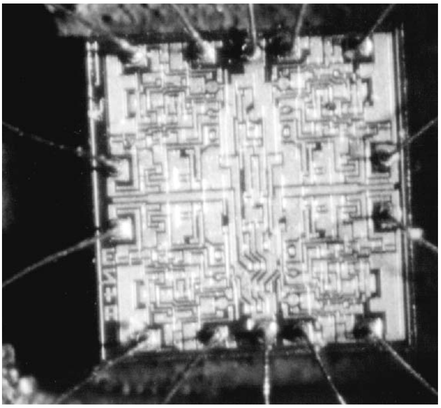
A team of physicists at Bell Labs, William Shockley, John Bardeen and Walter H. Brattain, took this research still further. They developed a device that, in highly simplified terms, consisted of two diodes mounted "back to back." For example, a layer of p-material sandwiched between two layers of n-material or vice versa. Electrodes, or connections, attached to the emitter and collector are fastened to the "outside" pieces, and another connector, to the base, is fastened to the "sandwiched" piece. Now a relatively large current flow between the two "outside" contacts could be controlled by a relatively small current through the "sandwiched" contact, or base. So the base is analogous to the grid



*DeForest DV-1 Audion of about 1922 (left) and Western Electric 205-D, which was a re-engineering of original Audion for telephone applications.*

of a thermionic triode valve.

This device could be used for switching, as a replacement for the slow mechanical relays, or for amplification of electrical signals. It was christened the transistor, and the configuration described above is known as a bipolar transistor. The first transistors were unreliable and of variable quality, but manufacturing techniques were improved until performance and consistency of manufacture equalled or surpassed those of their thermionic predecessors.



*Modern integrated circuit showing components and connections.*

## *New Horizons*

By the latter 1950s new semiconductor technologies were available, including the planar transistor, field effect transistor, metal oxide semiconductors and the tunnel diode. These found plenty of applications in biomedical, communication, military and, certainly, the computer fields. However, if the transistor had an enormous impact on the electronic industry, the birth of the integrated circuit in 1965 revolutionized it.

In this new technology a whole array of components such as diodes, resistors, capacitors and so on could be built, assembled and interconnected in just one piece of silicon crystal. Finally, over sixty years after the introduction of the crystal detector, the new technological field of microelectronics was born.

## SELECTED BIBLIOGRAPHY


1. Phillips V. J., *Early Radio Wave Detectors*, Peter Peregrinus Ltd.,1980.
2. Ryback J.P., "The Birth of the Vacuum Tube," *Popular Electronics*, Volume 8, No. 5, May 1991, pg. 40.
3. "An Age of Innovation," from *The World of Electronics* 1930-2000 by the editors of *Electronics* magazine, McGraw-Hill, 1981.
4. Fazano, Carlos Alberto, "Brief History of the Valve Audio Amplifier," *The AWA Review*, Volume 7, 1992.
5. Hazeau H.A.G., *Fifty Years of Electronics Components* 1921-1971, N.V. Philips Gloellampenfabrieken, Holland, 1991.
6. Ruckert Michael, "Preparation Of Semiconductors and Integrated Circuits by Using Metallographic Sectioning Methods," Struers A/S, Denmark.
7. Swartz, C. E. *Microstructure of Matter*, U.S. Atomic Energy Commission publication, Library of Congress catalog card No. 65-611766.
8. Gschaeidner K.A. Jr., *Rare Earths the Fraternal Fifteen*, U.S.Atomic Energy Commission publication, Library of Congress catalog card No. 65-60546.
9. Sievers, M.L., *Crystal Clear*, The Vestal Press Ltd. USA, 1991.
10. Dowd, Patrick, Bro., "The Nuvistor Story," pg. 26, *The Old Timer's Bulletin*, Volume 28, August 1997, No. 3.
11. *RCA Transistors, Thyristors, Diodes Manual*, Technical Series SC-15.
12. Constable, Anthony, *Early Wireless*, Midas Books, 1980, England.
13. *Radio Bygones*, August/September 1997 Issue, No. 48.
14. Stokes, John W., "Loewe In New Zealand," *N.Z.V.R.S. Bulletin*, Volume 8, No. 2, August 1987, pg. 4.
15. Fazano Carlos Alberto, "Collecting Vintage European Radios in Brazil," *OTB*, Volume 33, May 1992, No. 1.



## ACKNOWLEDGEMENT

*My sincere thanks to Jairo Cassoy for his support and advice regarding the preparation of several photographs used in this article.*