TRANSISTOR *Tales*

A series of three tales by Gregg Grant

PART 1

The Crystal Maze

Silicon is coming to the end of its usefulness as an Integrated Circuit (IC) manufacturing material. Already there are hints that the new substance Gallium Nitrate could well replace it in this role in the near future. It's time therefore to look back at a material which came to prominence only 50 years ago, yet in that period has completely revolutionised a century-old technology.

Early Days

Semiconductors quite literally run our lives. In fact life as we know it would be quite impossible without them. In cameras, night-vision devices, facsimile machines, TV cameras, medical electronic equipment and home entertainment generally, the semiconductor calls the shots.

There are a trio of properties that distinguish semiconductors from insulators and metals. These are ' . . the negative temperature coefficient of resistivity, the photo-electric effect and the use of semiconductors to achieve rectification.' [1] All of these properties - as table one shows - were discovered in the 19th century, but only thoroughly understood in the late 1940s.

In 1880, the French physicist Pierre Curie discovered that certain substances produce an electric current, as a result of pressure being applied to them. Conversely he found that, if he applied an electric current to the substances, their dimensions changed slightly. Furthermore, if the electrical potential applied varied rapidly, the substance would expand and compress in tune with this change. This effect Curie termed Piezo-electricity, from the Greek word for pressure.

Pierre Curie had used quartz in his experiments, but shortly other materials were found to have similar properties, for example Rochelle Salts and Galena; Pryon or Iron Pyrite and Chalcopyrite, or copper pyrite, a sulphide of copper and iron, in fact the commonest ore of copper.

By 1906, the new technology of radio had been firmly established, although for anything approaching reliable communication, a sensitive receiver was crucial. More importantly, the vital component in the receivers of the day was the detector, the device that untangled the intelligence - speech or music - from its carrier, the radio frequency signal. The radio engineers of the day spent a great deal of both time and money trying to make these detectors as sensitive as possible.

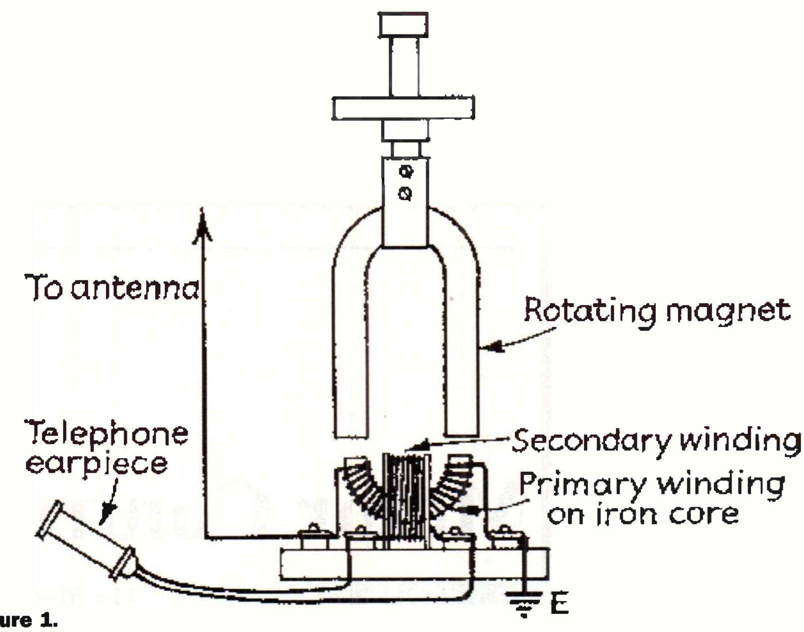

Figure 1.

Year	Discoverer	Discovery
1833	Michael Faraday	The negative temperature coefficient, which he noticed in silver sulphide.
1839	A.E. Becquerel	Observed a photo-electric voltage in an electrolyte.
1873	Willoughby Smith	Observed a photo-electric current in selenium.
1874	Ferdinand Braun	Observed rectification in some crystals, in his case metallic contacts to pyrites and galena.

Table 1: Early Semiconductor Discoveries

The Marconi Detectors

In 1895, the physicist Ernest Rutherford built a device capable of detecting radio signals over a distance of around ¾ of a mile. Five years later he proposed another form of detector, this time employing a moving band of steel tape, which could record the incoming signal.

Rutherford's work came to the attention of Marconi and, in 1902, the radio pioneer

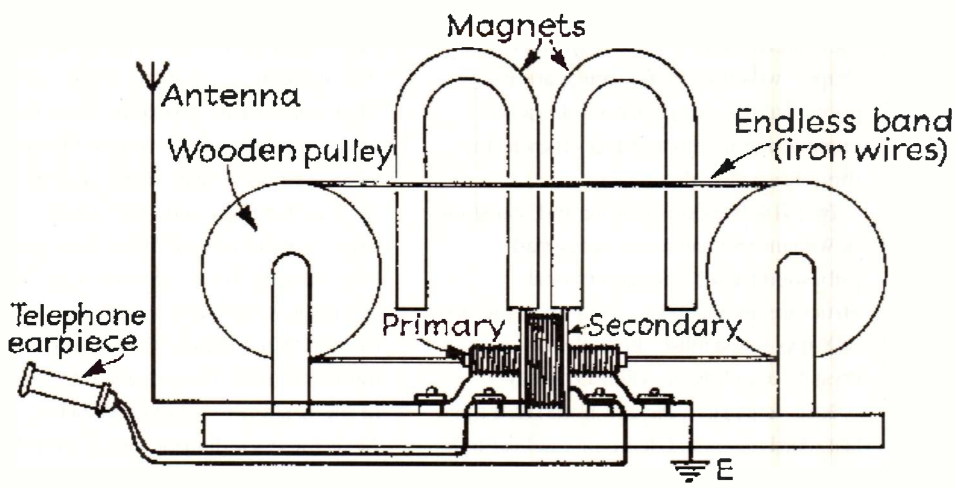

Figure 2.

three - before turning to oxidised steel. In July 1902, he found that putting pressure on the steel contact of his detector increased the received signal strength and, at the same time, appeared to reduce the accompanying noise. There was a problem however: the oxide coating was very thin and so easily penetrated.

By October, Pickard had hit on the idea of using magnetite instead of oxidised steel, which further improved reception. This convinced him that the use of oxides - magnetite, or lodestone, is a natural oxide of iron of course - was the way to go where signal detection was concerned.

This was the beginning of a quest that would be thorough. By early 1904, Pickard had already investigated selenium and lead oxide among other substances and recorded how the successful substances shared a common factor: they all had high specific resistance. By autumn, he'd added Chalcopyrite, Iron pyrite and Galena to his list of materials investigated.

Having read of a new product on the market - fused silicon - in December 1905, Pickard attempted to get hold of this material, feeling that a substance formed by the high temperature of an electric furnace

began experimental work to produce a commercially viable detector, based on Rutherford's research. The result was the detectors shown in Figures 1 and 2. The earlier of the two designs used a rotating magnet and stationary coils, whilst the second attempt was - in its way - a far more practical version of Rutherford's origination.

Known as the Magnetic Detector, this development '. . used an endless band of soft iron wires stranded together but insulated from each other, moving slowly past the poles of a pair of stationary permanent magnets.' [2]

As the internal clockwork drive moved the wire-band at around 7.5 centimetres/second (cm/sec), it was partially magnetised, due to the speed of the movement of the wire-band. On receipt of a signal at the antenna, the hysteresis of the primary coil was cancelled, it becoming fully magnetised with the lines of force appearing at a point opposite the magnet's pole pieces. This induced a current in the secondary winding, which fed the receiving headphones.

Marconi's 'maggie' as it rapidly became known among maritime radio operators, finally did for the earliest of detectors, the less-than-efficient Coherer. As a result it became a company standard, remaining in use for almost two decades.

Pickard and Perikon

In America too, research into the detection of radio signals was being pursued with the same drive and vigour that the Marconi company was giving to the matter.

In 1902, the American Wireless Telegraph and Telephone Company - the first such commercial outfit created in the United States - built two radio stations in New Jersey, one at Cape May and the other at Atlantic City. They also equipped a schooner, the Pleiades, with radio equipment so as to carry out experiments in radio communications.

The company also employed a 25-year old Massachusetts Institute of Technology graduate, one Greenleaf Whittier Pickard, to oversee these experiments. This would be the beginning of a long, determined search for a consistently reliable signal detector.

Pickard began by using a carbon-steel detector - like the one shown in Figure

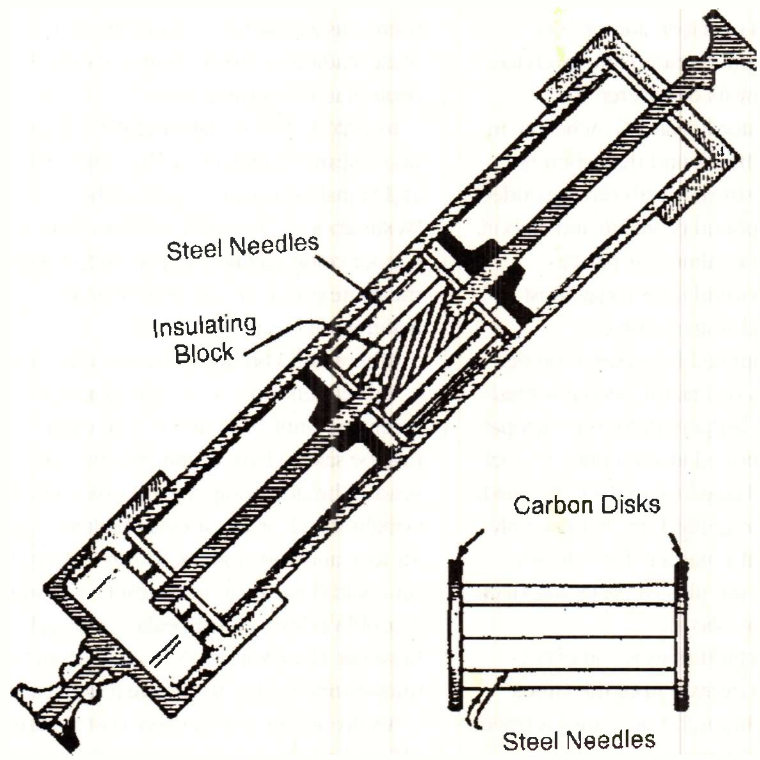

Figure 3.

would be very stable indeed. However, eight months passed before he was successful.

As Pickard had surmised, silicon proved to be the best of all the crystalline materials he'd tried so far. In 1907, he formed his own firm, the Wireless Specialty Apparatus Company, to market his silicon detectors on which he'd taken out patents.

In all, Greenleaf Pickard investigated no less than 31,250 combinations of substances in his search for a reliable detector. He even consulted the American mineralogist Richard Dana's 580-page masterwork A System of Mineralogy, in his search for substances, which could possibly be of use.

Consequently, his company marketed other detectors made from Pryon and Perikon, a detector consisting of zincite in contact with chalcopyrite. The word was an acronym, derived from PERfect pIcKard cONtact.

A General Takes A Hand

On the 26th March 1906, a retired American army general called Henry Dunwoody - who was working for the De Forest Wireless Company - announced his development of the Carborundum detector, an example of which is illustrated in Figure 4. This marked a new departure in electrical materials, flagging up '. . the existence of solid substances which did not obey Ohm's law, and which soon led to the development of a variety of forms of crystal detector which were to challenge the supremacy of the magnetic detector in no uncertain manner.' [3]

A compound of silicon and carbon, Carborundum was a trademark, given to the substance by its discoverer, the American inventor Edward G. Acheson, in 1891. Acheson had found that when he heated carbon strongly with clay, he ended up with a compound of silicon and carbon, or silicon carbide. Almost as hard as diamond, Carborundum is today most commonly used as an abrasive.

Dunwoody applied for a patent on his detector, which had nearly been invented by Pickard as it happened, for the material had been mentioned in a scientific journal but Pickard had failed to notice it. He made it plain that he regretted this, for not only was the material a 'natural' for detector experiments, it was also far easier to obtain at that time than silicon.

All of these materials were - in effect - crystals, a word derived from the Greek word for frost, Kryos, because they termed the symmetrical patterns they saw in snowflakes and hoarfrost Krystallos.

Another aspect of ice noted by the Greeks was its transparency. Consequently, when they discovered rocks with symmetrical shapes, which were also transparent - a good example being that staple radio engineering material quartz - they termed them Krystallos also.

By 1915, the British father and son team of William and Lawrence Bragg had published their X rays and Crystal Structure, in which they described the use of X rays to establish the make-up of crystals, a technique still used today.

Four years later, Pickard noted that the last word on crystal detectors had yet to be written. In fact most of the crystalline substances already looked at were employed in the emerging communication/home entertainments field, and a number of engineers sensed that there was a clear way out of this crystal maze leading to greater things, if only they could find the turning point.

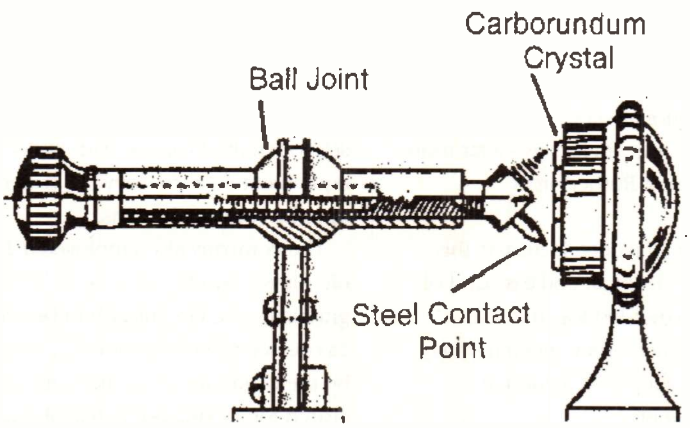

Figure 4.

In 1926 L.O. Grondahl and P.H. Geiger, two research engineers at the Union Switch and Signal Company - a part of the Westinghouse Corporation - invented the copper oxide rectifier, an early step towards the more extensive use of crystalline materials in electronics.

Where radio broadcasting was concerned '. . crystal sets were to outnumber (valve receivers) until 1927, and to that extent may be said to have dominated the early years of broadcasting. A good one could be bought for £2 or £3, or easily built at home for less, and cost nothing to run.' [4] A crystal set could drive a pair of headsets, although it couldn't drive a loudspeaker. You had; however, to be within 15 to 20 miles of the transmitting station to receive a signal at all.

A valve set, by comparison, cost at least £15 and required a new High Tension, or HT battery every few months. On top of this, the two - or sometimes three - lead-acid accumulators providing the Low Tension, or LT, current for the valve heaters needed recharging on a weekly basis. There were other problems too; one of which was valve replacement. One of the most common valves of the period - the R valve as it was termed - had a life expectancy of around 100 hours only.

No matter, the development of the electronic valve was a big improvement over the 'Cat's Whisker' and so scientific interest in semiconductors - even the best of them, silicon - waned somewhat. Nevertheless it did not vanish entirely and the increasing use of crystalline substances spurred further scientific - as opposed to engineering - investigation into the mysterious world of these materials.

Given the extensive use of crystal sets at this time as well as the number of amateur radio enthusiasts, it seemed surprising that no-one did successfully navigate the crystalline maze, at least superficially. Yet it would be wrong to imply that there was no attempt at advancement. In the five years between 1926 and 1931, much of the theoretical concepts of semiconductors were developed and it's this facet - among others - we'll look at next month.

References

1: Atherton, W.A. (1984): From Compass to Computer. San Francisco Press Inc., San Francisco. Ch 10, Page 237.
2: Baker, W.J. (1970): A History of the Marconi Company. Methuen & Co., Ltd. London. Ch 7, Page 75.
3: Ibid [2], h 13, Page 120.
4: Geddes, Keith & Bussey, Gordon (1991): The Setmakers: A History of the Radio & Television Industry. BREMA, London. Ch 1, Page 16.