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Transistors and Cold Fusion - Part 1

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Much of this paper is based on the book *Crystal Fire*, [1] a good introduction to the history of semiconductors.

The history of transistors teaches many lessons about how cold fusion might develop and what should be done to help it along.

Transistors are physically similar to cold fusion devices. In fact, some of the earliest experimental transistors were immersed in electrolyte with a counter electrode to neutralize the surface barrier. [2] Transistors and cold fusion cathodes are both small, low temperature, solid state crystalline devices that replace large, hot, plasma or vacuum-state devices -- triode vacuum tube amplifiers and tokamak reactors. Many of the specific hurdles overcome by early transistor researchers are directly applicable to cold fusion, especially problems with reproducibility, contamination and materials. George Miley [3] and others think that commercial cold fusion cathodes may be fabricated by using modified semiconductor manufacturing equipment, especially thin-film or electroplating apparatus. Cold fusion cathodes do not require precise placement of components the way integrated circuits do, but they do require precise control of materials and composition, extreme cleanliness, automated production, and packaging in plastic or ceramic containers to exclude contamination.

Transistors and cold fusion were developed after decades of theoretical speculation, false starts, and precursor devices. Paneth and Peters conducted cold fusion experiments with palladium in the 1920s; J. E. Lilienfield received a patent for a semiconductor field-effect amplifier in 1930, which probably would not have worked. Development of both transistors and cold fusion was delayed for years because there was no broad theory to guide research, and basic questions remained unanswered. Until 1952 it was not clear whether the transistor effect occurs in the bulk of the material or on the surface, and this is still a major unanswered question in cold fusion. Fleischmann believes the effect occurs in the bulk, but most other scientists say it happens at the surface or near surface layers. They point to evidence such as damage found near the surface and the fact that helium and tritium are generally found in the effluent gas, not trapped in the metal lattice.

Cold fusion has been far more controversial than semiconductors, and more difficult to replicate, but semiconductors did cause controversy during the first 25 years of development. In 1931, Wolfgang Pauli said: [4]

> I don't like this solid state physics . . . though I initiated it . . . One shouldn't work with semiconductors, that is a filthy mess; who knows whether they really exist.

Problems with Contamination and Reproducibility

Difficulties with contamination have always plagued the semiconductor industry, and they are major problem in cold fusion. Minute quantities of impurities, called dopants, must be added to silicon to make a transistor. Other impurities must be rigorously excluded, because they poison the reaction. It is likely that similar dopants enhance the cold fusion effect.

Before there was a theory, the only way to begin learning how to made an effective semiconductor amplifier was to look at samples of solid state material that did things similar to amplification, like rectifiers and photovoltaic converters. Subtle differences in materials were important. Copper oxide rectifiers worked best when made with copper from a particular mine in Chile. In 1938, a piece of silicon that acted as a photovoltaic device was discovered fortuitously. The chemical makeup of this sample was investigated with the best mass spectroscopy available at the time. Since cold fusion scientists have no effective theory, they should concentrate on examining and analyzing materials from effective cathodes.

One of the myths spread by opponents of cold fusion is that soon after things are discovered, they become easy to reproduce. Transistors were extremely difficult to reproduce for many years. One scientist recollected, "in the very early days the performance of a transistor was apt to change if someone slammed a door." In the mid-1950s transistors cost $16 apiece compared to the $3 vacuum tubes they were designed to replace. Integrated circuits were even worse. In the 1980s, after three decades of the most intense high-tech R&D in history and hundreds of billions of dollars of investment in transistor technology, more than half of the computer chips coming off production lines in the U.S. were defective and had to be scrapped. (Production rates were better in Japan.) In the late 1990s, 10 to 20% of chips fail. [5] I will have more to say about this in Part 2.

Riordan and Hoddeson describe contamination problems seven years after intense semiconductor research began: [6]

> For several years during the early to mid-1950s, Shockley (and others) spoke of a mysterious class of substances that he dubbed "deathnium," which somehow crept into semiconductors and acted as traps for holes, gobbling them up and further shortening their already-too-brief lifetimes. After much consternation and head scratching, trace atoms of copper were finally identified as one of the culprits. They were thought to have found their way from laboratory doorknobs to germanium surfaces on the unwashed hands of unwitting technicians!

An Educated Guess about Crystal Grain Size

Most metals are made up of randomly oriented microscopic crystals (also called crystallites or grains). Metal with a many small grains is harder than metal with fewer, larger grains. A blacksmith heats iron to reduce the number of grains by melting them together, making the iron malleable. Then he pounds it with a hammer to increase the number of grains, making it more amorphous or polycrystalline. Some materials, such as gems, are made of a single large crystal. In 1948 it was discovered that a transistor made from a single crystal of germanium, with no grain boundaries, worked much better than amorphous germanium, because grain boundaries interfere with the transport of electrons. Cold fusion works best the other way. Recent work by De Ninno et al. shows that cold fusion cathodes work better with small grains, each no larger than 50 microns across, apparently because the grains load more deuterium without fracturing from the buildup of mechanical stress. [7] De Ninno concludes that variations in grain size and shape cause large differences in performance, and this factor alone may explain all of the variability in performance. This did not surprise experienced electrochemists. During ICCF7, the NEDO Japanese researchers described how they had made great efforts to fabricate large grain cathode metal. Robert Huggins heard the presentation and said to me, "that's a splendid effort but it is just the opposite of what they should be doing." Huggins prepared his first successful cold fusion cathodes in 1989 by pounding the metal with a hammer to make it more amorphous. [8]

At Bell Labs in 1948, Gordon Teal made an educated guess that a single crystal germanium would be needed for predictable, effective transistors. Teal thought he could develop a process to fabricate single crystals of far greater purity than any then in existence. William Shockley, the head of transistor research, was headstrong and did not appreciate how important this was. At first he paid no attention to Teal's work. Teal had to pursue the project at night with "bootlegged" equipment. He would unplug his apparatus every day, roll it into a closet, and work on his official assigned task instead, which is how many cold fusion experiments are performed.

In 1949 Teal gave a sample of his germanium crystals to a chemist in the newly formed semiconductor research group. The chemist tested the electron and hole mobility of the crystal and found that performance was 20 to 100 times better than that of the conventional, polycrystalline samples. "As word of this success percolated through the semiconductor group, Shockley finally began to sit up and take notice of Teal's work. By late 1949 he had to admit he had been wrong. . . . Soon Bell Labs would have an entire group devoted to growing single germanium crystals." [9] A few years later Bell Labs developed zone refining, which made materials 1000 times purer than any previous technique. This alone would have been sensational, even without transistors. It was one of many breakthroughs needed to make transistors practical. The transistor was not "one" innovation; it was the culmination of a series of related and directed innovations triggered by the 1948 breakthrough. You could not make a practical transistor without ultra-pure single crystal germanium (later, silicon), but no one thought to make ultra-pure single crystal germanium until the first crude, unreliable prototype transistor was demonstrated. No one investigated small grain palladium in detail until many years after 1989. Cold fusion will not succeed until many other related, directed innovations are untaken to support it, which will cost huge amounts of money.

Lessons

The early history of transistors teaches many lessons about how science works and what to expect in the early stages of ground-breaking research.

Prototype inventions are often crude, unreliable, and makeshift. The first point contact transistor was held in place with a spring fashioned from a paperclip, which literally pushed a point down to keep it in contact with germanium. Kilby described the first integrated circuit: "it looked crude, and it was crude." Riordan and Hoddeson add, "these prototypes were extremely awkward realizations of the much more sophisticated ideas he penned into his notebook two months earlier. But the first prototype of an important technological idea is often crude -- witness the first transistor." [10]

Some experiments are too crude. Shockley was a theoretician, not an experimentalist. One day in 1940, a scientist named Wooldridge found him fiddling around in the lab with a piece of oxidized copper, which "had apparently been cut out of some very old copper back porch screen with very dull scissors." Shockley was trying to position wires so they would barely touch the green oxide coating. He hoped to adjust the voltage applied to the mesh to control the current flow. In other words, he was trying to make a crude transistor. Wooldridge later wrote: "so here he had the three elements of a transistor, these two wires and the copper screen. Of course, he was *orders of magnitude* away from anything that would work!" [11] Most of the 1989 "replications" of cold fusion were equally laughable. Critical electrochemical parameters like loading and open circuit voltage were not measured; materials were not analyzed before or after the run. This is flailing in the dark, not science. You might be orders of magnitude away from anything that will work, or you might be on the verge of success. You have no way of knowing, and even if you do achieve success, you will be unable to replicate the effect.

Scientists must pay close attention to inexplicable phenomena which may look like instrument errors at first. They should not dismiss weird, marginal, unexpected, anomalous phenomena. In the 1920s silicon crystal radio detectors developed a bad reputation. "Variability, bordering on what seemed the mystical, plagued the early history of crystal detectors and caused many of the vacuum tube experts of a later generation to regard the art of crystal rectification as being close to disreputable." [12] In 1938 a scientist named Becker at Bell Labs tried to measure the conductivity of silicon rods. When the probe was moved from one spot to another, conductivity varied wildly. One of the rods was "so erratic that no consistent values could be reported." The rod was put aside and forgotten for a year until Russell Ohl examined it carefully and discovered that it acted as a photovoltaic cell, converting light into electricity. This was the first time anyone had seen the photovoltaic effect in silicon. It was the real start of AT&T''s research in semiconductors. Ohl later said that Becker's career suffered: [13]

> He had that active silicon in his department, in his hands, and he didn't find it . . . That is what you are up against in research. You've got to watch for things like that, for something unusual. If that happens, you have got to learn to recognize it.

Not eloquent perhaps, but it expresses an essential truth which many scientists pay lip service to, while in practice they ignore. Many scientists have ignored evidence for cold fusion. In a few cases they have actively tried to bury it.

You must be careful not to fool yourself. After the triumphant in-house demonstration of the first functional transistor in 1948, one of the observers cautioned the discoverers: “look boys, there’s one sure test of an amplifier, that you aren’t kidding yourselves. An amplifier, if fed back on itself with a proper circuit, will oscillate. This shows that it is really producing power -- more than you put into it.” [14] The next day, Brattain performed the feedback test and confirmed that the device did oscillate. Many cold fusion scientists have failed to perform simple calorimetric tests which would reveal that their devices are “really producing power” and other simple tests such as autoradiographs, which confirm that the effect really is nuclear.

Scientists should cooperate. While manufacturing radar sets and other electronics during World War II, AT&T learned the value of close cooperation between theoreticians, experimentalists, and production line workers. The economic boom and postwar office-space crunch helped to prolong this cooperation. Bell Labs rushed to hire many new scientists while it completed a new laboratory. When Bardeen joined Bell Labs in 1945 “office space was extremely scarce . . . So employees were being asked to double up . . . Bardeen didn’t mind; he liked the company of experimentalists. Here was an opportunity to glance over their shoulders and talk about the data as they collected it.” [15] This spirit of cooperation was essential to the rapid development of transistors.

Success Was an Accident

Success in research is often the unlikely result of a series of accidents. Consider some of history’s might-have-beens. Gordon Teal worked at night on his “bootleg” crystal growing experiments and during the day on his regular assignment. His wife grew upset at this overwork, and asked him to cut back. She might have prevailed, or he might had grown discouraged and burned-out on his own. Or he might have missed the opportunity to show the chemist his single crystal sample. Shockley might have remained characteristically obstinate, continuing to ignore Teal’s research. This one oversight by Shockley might have held back the development of transistors for years. Thousands of technical decisions and choices must be made in the course of developing a commercial product, and each might be a wrong turn or a dead end. That is why research must be done by many different independent laboratories, at different corporations and universities. One person or one funding agency committee cannot be placed in charge. One person, no matter how brilliant, may guess wrongly and lead the whole project into a dead-end. Competing ideas must be tested, even ideas the experts consider crazy.

In the Epilogue, Riordan and Hoddeson describe the mix of personalities and institutions needed to bring about the transistor: [16]

> None of these men [Shockley, Bardeen and Brattain] could have invented the transistor alone. But their lives intersected at a unique American institution during a peculiar moment in history to make it possible, even likely. Nothing on the scientific landscape at the time compared with Bell Labs. It combined intellectual power equal to that of the nation’s best science departments with technical resources and manpower that none of them could come close to matching. When these tremendous resources became focused on developing practical products based on wartime advances in semiconductor technology, something big had to happen . . .
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> Each man’s shortcomings were compensated by the others in this multidisciplinary environment. With his single-minded focus on “trying simplest cases first,” Shockley would never have conceived the unwieldy point-contact gadget that opened the door to the transistor . . .
>
> . . . Almost as important as the transistor’s invention are the techniques of crystal growing and zone refining, which allow one to fabricate large single crystals of ultrapure silicon and germanium. Without these crystals, the industry would not exist.

This is contradictory. The mix of personalities was unlikely; the postwar boom was a “unique moment in history” which we hope will never be repeated (if it takes a war to trigger such a moment). Yet the authors conclude that “something big had to happen.” They seem to think the invention was unlikely yet inevitable. Was the transistor truly inevitable? Where would we be without it? Is any innovation inevitable and unstoppable? I will examine these issues in Part 2.

Footnotes

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1. M. Riordan, L. Hoddeson, *Crystal Fire, the Birth of the Information Age*, (Norton, 1997)

2. Riordan and Hoddeson, *ibid*., p. 130

3. Private communication, 1999

4. L. Hoddeson, E, Braun, J. Teichmann, and S. Weart, *Out of the Crystal Maze*, (Oxford Univ. Press, 1992), p.121

5. S. Lohr, “Suiting Up for America’s High-Tech Future,” *New York Times*, December 3, 1995

6. Riordan and Hoddeson, *ibid*., p. 219

7. A. De Ninno, “Material science studies aimed at improving the reproducibility of the heat excess experiments,” Proc. ICCF7, p. 103

8. M. Schreiber et al., “Recent Measurement of Excess Energy Production in Electrochemical Cells Containing Heavy Water and Palladium,” Proc. ICCF1, Table 1, 2 and 3, p. 54

9.Riordan and Hoddeson, *ibid*., p.179

10.Riordan and Hoddeson, *ibid*., p. 259

11. Riordan and Hoddeson, *ibid*., p. 86

12. Riordan and Hoddeson, *ibid*., quoting F. Seitz of AT&T, p. 92

13. Riordan and Hoddeson, *ibid*., quote from Ohl, p. 96

14. Riordan and Hoddeson, *ibid*., p. 140. Note, however, that an amplifier does not literally produce power. It transfers energy from the power supplies to the output, increasing or decreasing power depending on the control current. All energy originates in the electric power supplies. With cold fusion the energy originates in the cell. Cold fusion cells sometimes resemble amplifiers. When the cathode current density increases, deuterium loading usually increases, and after a while the cold fusion power may increase proportionally, assuming other control parameters remain the same.

15. Riordan and Hoddeson, *ibid*., p. 120

16. Riordan and Hoddeson, *ibid*., p. 280