Episode 4

Invention of Integrated Circuits

The time machine takes us to the latter half of the 1950's, and I now describe the societal background when the IC was invented and its dramatic development story.
The role which IC invention has played in building a ubiquitous society today is so big beyond my description.
Craig Barrett, then Intel Chairman, said in his response to the questionnaire survey commemorating the 40th anniversary of IEEE Spectrum magazine in 2004 "Without ICs, PCs and mobile phones would have been something like big buildings." This is a clear and direct description of how great an impact the IC invention had to our lives. Today's ubiquitous society is brought about exactly by the invention of IC and subsequent technological innovations.

In the latter half of the 1950's, after ten years since the invention of transistors, semiconductors were starting to spread to various fields such as military applications, computers, and consumer equipment. The increase in the number of interconnections between the parts became a serious problem as the system became larger and more complicated. This was because the performance, cost,
reliability, size, etc. of the system were greatly restricted by increasing number of wirings and soldering of the parts.
This problem was called "Tyranny of Numbers", which was a common problem of the industry, and its countermeasure was required. The technology development was advanced from various angles. The munitions industry took this issue most seriously. In the era of the Cold War, the two major powers, the United States and Soviet Union, competed fiercely how to increase the flying distance of the intercontinental ballistic missiles. The need for the longer distance was concisely expressed in the following words: "One-pound lighter, one mile farther". In other words, it was an expression of a strong desire that "If a missile were lighter by one pound, it would fly one mile farther".
In order to challenge such problems, TI carried out a joint development project with the military group, and their method was called micro-module. Electronic components such as transistors, resistors, and capacitors were mounted in ultra-compact dimensions. Jack Kilby was one of its development members of TI. But he had questions about this method, and spent days pondering the unique method that would exceed this idea. The result of this was the concept of "monolithic integration". "Monolithic" is an adjective meaning "single stone", and it was a method of integrating various kinds of electronic parts on a single semiconductor substrate. This is the basic concept of today's IC.

Kilby invented the IC on July 24, 1958. As you can see from this date, that day was the height of summer, and most colleagues were in their summer vacation. At the age of 34, since it was still very soon after he moved to TI from another company, he was not able to get a vacation and he was left alone in the laboratory.
The great invention of the century was born just at this occasion.

Based on this idea the project for making prototype of the oscillation circuit started immediately. The prototype was completed on September 12 of the same year, and it worked fine while the executives were watching. TI adopted the monolithic IC method invented by Kilby, as the major solution, instead of the micro-module.

On the other hand, Fairchild's Robert Noyce devised the new concept of IC based on planar technology on January 23, 1959, almost half a year later than Kilby's invention, and he wrote it in the research note. Despite being late for Kilby, the invention of Noyce involved basic elements indispensable to the realization of today's IC. That is, in the invention of Kilby, the connections between the elements on the substrate were made by bonding wires, but in the Noyce method, it was done by processing the metal film deposited on the oxide film of the substrate. From today's viewpoint, we can regard the Noyce method much more elegant and practical.

Is the inventor of the IC Kilby or Noyce?
Over the next ten years there was a court struggle over the attribution of patent rights. The history of court battle during that period is described in detail in "The Chip" written by T. R. Reed*, but I will only introduce the outline here to simplify the matter.
*T. R. Reed "The Chip", Random House Trade Paperbacks, 2001

Although Noyce was late for Kilby at the timing of actual IC invention, Noyce applied for the patent earlier than Kilby, and the first patent right was given to Noyce. However, since Kilby could prove that the description in the research note was earlier than Noyce, the patent right turned into Kilby, but the dispute was not settled here. After this, hearings were conducted on the patent positions of both of them, and one of the semiconductor authorities testified that "it is not realistic to make ICs only with Kilby patents". The judgment once again turned on to the side of Noyce. The Kilby side fought back against this with their total power.
In this way, while the dispute was repeated back and forth, negotiations were held between the top management of TI and Fairchild, and they finally agreed that the credit of the IC invention to be shared by Kilby and Noyce.

Now the time machine flies into the future from this time, and it was October 1991. When Kilby came to Japan, I had an opportunity of having dinner with him with Advantest's special arrangement. The intense impression that I first received was his dignified shape, much taller than myself and I had to look up him when hand shaking. And without giving himself airs, he spoke slowly with a thick, low voice. There was an atmosphere like a wide river in the plain flowing slowly and quietly. It was truly an honor to be able to listen directly to the one who made a great invention of the century, talking about his invention stories nostalgically. The picture below was taken at this time.

Photo 4.1 Jack Kilby (left) and the author (October, 1991)

Time passed and Kilby won the Nobel Prize in Physics in 2000. He became a single winner, probably because Noyce had already passed away at that time. In fact, he himself said that “Noyce had a similar idea about IC, and invented the means of realization”, so if Noyce had been alive, the Nobel Prize would have been shared between the two of them as the patents were shared.

Fairchild first released the IC as a product in 1961. It was a bipolar IC using bipolar transistors as active elements. Following this, various technological developments were conducted in the field of ICs, which formed the core of semiconductor technological innovation. In 1964, MOS IC based on MOS transistors was announced from TI and others, followed by RCA’s announcement of CMOS IC in 1968.
CMOS IC had characteristics of extremely low power consumption, but its speed was slow and cost was expensive. Therefore, it was initially limited to special applications such as military use, and was regarded as a so-called niche technology. It was the application to watch and calculator in Japan that opened the way to mass market of CMOS IC.
Later in the 1970’s, Hitachi developed a high-speed CMOS technology with competitive speed to NMOS technology, the fastest device at the time, which resulted in the “high speed, low power, and cost competitive IC”. Today, CMOS IC has become the mainstream semiconductor device, and we will revisit these backgrounds in the later section.

What is the lesson learned from IC inventions?
In recent years, technology development of semiconductors requires hundreds of engineers and hundreds of millions of dollars. We cannot simply compare the time when the IC was invented and today, but the inventions of Kilby and Noyce were both accomplished by deep insight and strong imagination of single individuals without relying on many resources. In developing new technology, we must keep in mind that insight and imagination for the future is more important than the amount of money and the number of people.

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