Oral History of Kiyoo Itoh

Interviewed by:
Douglas Fairbairn

Recorded July 18, 2016
Tokyo, Japan

CHM Reference number: X8791.2019

Fairbairn: Okay. So we will begin this oral history. It's currently about 6:30 p.m. in San Jose, California. I'm Fairbairn and it is Monday, July 18th. And in Japan, what time is it there?

Itoh: It is 10:00...

Fairbairn: 10:37.

Itoh: 10:44, yes.

Fairbairn: Yes, 10:40.

Itoh: Yes.

Fairbairn: 10:40 a.m. in Japan on Tuesday, the 19th. So we are recording this with a video camera and recording in Japan. And I am talking from San Jose, California. So welcome. My name is Fairbairn and I am here to interview Dr. Itoh, who has a very interesting and significant background, especially in the area of dynamic random access memory design or DRAM design.

Itoh: Yes.

Fairbairn: And I am very interested to hear about your contributions and developments over your long career, especially in that area.

Itoh: Thank you.

Fairbairn: So thank you for joining us.

Itoh: Thank you.

Fairbairn: So as we begin all of these oral histories, we like to hear first something about you - where and when you grew up, what type of family life you had and how any of those early life experiences might have influenced or steered you towards a career in technology.

Itoh: Yes.

Fairbairn: So if you could just begin by telling us where you were born -

Itoh: Yes.

Fairbairn: - and something about your family life.

Itoh: Yes. I was born in Miyagi Prefecture, the northern-east of Japan on January 5, 1941. So I am now as old as 75. And my family consisted of 10. My brothers and sisters in total is 10, as many as 10.

Fairbairn: Ten. So you have 11 children?

Itoh: And I am a - I am a youngest, last one.

Fairbairn: So there were 11 children total in your family?

Itoh: 10.

Fairbairn: Ten, total.

Itoh: Yes.

Fairbairn: You were one of 10.

Itoh: Yes. I am the last one.

Fairbairn: My goodness. At that time, during the war and after the war, that must have been a struggle for your family to raise such a large family.

Itoh: Yes, so along with such a many brothers and sisters, I understand that I got ambitious and challenging spirit which may be unconsciously and gradually developed in my early life in poverty with many children, understand. So, at that time, being engineer was considered to the best way to meet my such a spirit, you know. It is very natural.

Fairbairn: So what was - what occupation was your father? What did he do?

Itoh: Farmer.

Fairbairn: Farmer?

Itoh: Yes.

Fairbairn: And did all the children work on the farm?

Itoh: Yes, I think so, including me. In my young age I must work in the field.

Fairbairn: So you learned about hard work with your hands very early age.

Itoh: Yes. Of course.

Fairbairn: That was - that was the only way to survive.

Itoh: Yes. So it is natural to say that to escape from such a life, I must become something - something special, you know? It was being engineer.

Fairbairn: Yes.

Itoh: To get money.

Fairbairn: So - so clearly, you have a very distinguished career. Just briefly, did any of your siblings, any of your brothers or sisters pursue a technology career?

Itoh: I understand that this is - my family was just a farmer, so nobody got involved in high technology. My answer meets your question?

Fairbairn: Yes. I was wondering whether any of your brothers or sisters went to university or pursued high technology.

Itoh: No. Only one.

Fairbairn: Only one?

Itoh: To go to university, by supporting, with supporting some money from my sister. It was strongly supported. So just only one, myself.

Fairbairn: Only one child?

Itoh: Oh, yes.

Fairbairn: Well, congratulations.

Itoh: Congratulations.

Fairbairn: So, when you entered the university -

Itoh: Yes.

Fairbairn: - Did you know what you wanted to study?

Itoh: Yes, I wanted to study electronics because at that time electronics was emerging technology, you know. It is - 50 years ago, electronics is still premature, but emerging, that is why.

Fairbairn: Right. Good. What year did you enter the university?

Itoh: Oh I went to Tohoku University. You know Tohoku University? It is, I understand, one of the prestigious university in Japan which is close to my hometown. So only I can did at that time is go to near university because I was very poor.

Fairbairn: Right.

Itoh: I couldn't go to Tokyo and Osaka. Only I could go to Sendai, very close to my hometown.

Fairbairn: Did you live at the university or did you live at home while you were attending the university?

Itoh:
Oh, yes. I had daily life at Sendai. Dormitory, you know?

Fairbairn: Dormitory?

Itoh: Yes, dormitory.

Fairbairn: Yes. So you thought that electronics was interesting because it was an emerging technology.

Itoh: Yes.

Fairbairn: Did you have any - did you have any professors that encouraged you along that path?

Itoh: Yes. I had only one professor who fostered me by giving a very exciting theme and then letting me free. So there I could get independent spirit, you know. It is logical?

Fairbairn: Oh yes. You had a - you followed your own path.

Itoh: Yes. That is right.

Fairbairn: So did you -did you - were you aware of semiconductor electronics or transistors at that time, or not yet?

Itoh: Yes. In - at Tohoku University, we learned the semiconductor from Professor Nishizawa. Do you know - do you know Professor Nishizawa? Very, very famous in Japan.

Fairbairn: No, I am afraid I do not.

Itoh: But unfortunately I attended only two days. Because I, at that time, felt semiconductor is very difficult to me. That is why I went to magnetic field. But it is very

strange. Nowadays I am involved in the semiconductor. But at that time, semiconductor was very, very difficult to me.

Fairbairn: It was very, very difficult?

Itoh: Yes. Because, you know, PN junction and so on. It is very, very difficult to understand. So I gave up at that time learning semiconductor. So I decided my thesis on magnetic, not semiconductor, magnetic.

Fairbairn: Magnetic memory? Or…

Itoh: No, it is magnetic - this is not the magnetic memory. This is just parametric amplifier with nonlinear magnetic devices. So, at that time, I am very - I was very interested in the scheme of amplification by utilizing nonlinear effect. It was very exciting at that time.

Fairbairn: And so this was for, like, core memory? Or...

Itoh: No, . When - during university I didn't learn any magnetic memory. Only parametric amplifier.

Fairbairn: Oh, I see.

Itoh: After entering - after joining Hitachi, I started to learn magnetic memory.

Fairbairn: I see.

Itoh: Okay?

Fairbairn: So, let us talk about that. So you graduated from Tohoku University.

Itoh: Yes.

Fairbairn: And what year did you graduate?

Itoh: Oh. I graduated in 1963.

Fairbairn: 1963?

Itoh: Yes.

Fairbairn: And you had a - that was a bachelor's or it was a PhD.

Itoh: No. It's just a - not PhD, not master, it was bachelor..

Fairbairn: Okay. So bachelor's degree in 1963. And -

Itoh: Yes. I got a PhD 16 years later.

Fairbairn: Yes.

Itoh: Because we could - we couldn't get any diploma during graduate, you know, student. This very confusing?

Fairbairn: Yes. So -

Itoh: Anyway, I graduated - yes, I stayed the university only for four years.

Fairbairn: Yes.

Itoh: And then joined to Hitachi. -

Fairbairn: You joined Hitachi in 1963?

Itoh: Yes.

Fairbairn: And you decided to join the research laboratory.

Itoh: Yes, of course.

Fairbairn: And why did you -

Itoh: Because during - while I stayed at the university, I was - I am very exciting for the high tech. For example, parametric amplifier. So, at that time, I am very - I was very interested in the high tech. So when joining Hitachi Central Research Lab, that is why I chose Hitachi Central Research Lab to continue research.

Fairbairn: And did you consider other companies like NEC or…

Itoh: No. Only Hitachi.

Fairbairn: Only Hitachi?

Itoh: Yes. Because I understand at that time it is a very - one of the most prestigious research facility in Japan.

Fairbairn: I see.

Itoh: Yes.

Fairbairn: Okay, good. So what were the - what were your first assignments or jobs when you joined Hitachi?

Itoh: It is just magnetic core memory at first. Then move it to the magnetic thin film for large computers. So, in fact, I was involved in the development of large computer, Hitachi large computer, using such a magnetic memory.

Fairbairn: So when you say “thin film”, was that used for, like rotating disc drives, or was that some other technology?

Itoh: Yes. I understand that we are the first group that industrialized magnetic thin film for cache memory of large computers. But it was very exciting.

Fairbairn: So what type of memory?

Itoh: Magnetic thin film. Magnetic thin film memory.

Fairbairn: Oh, I see. Okay. And -

Itoh: And at first - at first, I involved in the magnetic core memory and then moved to magnetic thin film memory. Two kinds of magnetic memories.

Fairbairn: Okay. All right. So how long did you work on that and when did you change to working on semiconductors?

Itoh: About eight to 10 years.

Fairbairn: So you started working in semiconductors in the early 1970s?

Itoh: Yes. In 1970 I started to develop semiconductor memory.

Fairbairn: And why did you change?

Itoh: This is, you know, this is due to advanced memory technology of United States. Do you understand? So, at that time, I couldn't help changing my job from magnetic memory to semiconductor memory because we were behind, much behind, from United States makers like Intel, TI, IBM and Mostek. So we, Hitachi, must change our memory technology from magnetic memory to semiconductor memory.

So, at that time, I was entrusted with developing 4-kilobit DRAM without any knowledge about semiconductors. Can you imagine? Without knowing them. Because when I was in the university - I dislike - disliked semiconductor. But after that, I couldn't help changing my job to semiconductor. I couldn't tell the story without tears.

Fairbairn: So, were there many other people or were you sort of the lead person in - working on semiconductor memory at the time?

Itoh: Yes. I understand in my company nobody wanted to go into semiconductor memory because there is a big gap between United States and Japan. Nobody didn't like to change - such a drastic change.

Fairbairn: Right.

Itoh: I was very slow and not smart at that time. So I must change to the different field, you know.

Fairbairn: Sounds like you were very smart.

Itoh: Eventually, yes.

Fairbairn: Yes.

Itoh: Thank you.

Fairbairn: So, was there a particular thing like - was it the - Intel's announcement of the 1K dynamic RAM which caught their attention and -

Itoh: Yes. As you know, in 1970 Intel announced their 1-kilobit three-transistor DRAM. So, in fact, I evaluated their DRAM and I went to Santa Clara to see - to see a very famous, you know, person, Dr .Noyce, a founder of Intel. He is a very famous person from Fairchild. Anyway, I met the historical person, to discuss about his DRAM.

Fairbairn: And then?

Itoh: And almost simultaneously IBM announced their bipolar memory. So considering such a rapidly changing situation, Hitachi must change to the semiconductor memory. So, at that time, I was a victim of, you know, history.

Fairbairn: But you were the beneficiary - the victim at first and the beneficiary later on. So was it - was the decision to focus on semiconductor memory - did that come from semiconductor people or from the computer people who needed the product?

Itoh: Yes, at that time, top - almost top management decided. So the semiconductor memory is best way to go. This is a top decision at that time, I think.

Fairbairn: Okay.

Itoh: Yes. Because it -

Fairbairn: And so, did you -

Itoh: Because it is a too much drastic change.

Fairbairn: Yes.

Fairbairn: Did you begin work on a 1K memory or a 4K memory?

Itoh: No, 4K.

Fairbairn: 4K?

Itoh: Yes.

Fairbairn: And did you do any - you presumably did some research and so forth, but did you get any specific information from U.S. companies like Intel or Texas Instruments or Mostek? Did they -

Itoh: Yes, of course. I got valuable information from such companies at major conferences.

Fairbairn: Right.

Itoh: So I got a lot of information. By using information from international conferences.

Fairbairn: I see. And so, when you developed the 4K dynamic RAM, was it competitive technology-wise with the ones from U.S. companies or - tell me about the comparison between your first product and what others were selling?

Itoh: This - my 4K is eventually - eventually failed because no - that is not accepted in the market because chip size is big and memory cell consisted of three transistor. So this is -

Fairbairn: I see.

Itoh: My design made the chip size bigger and bigger. And meanwhile, TI announced one-transistor DRAM.

Fairbairn: Right.

Itoh: So, this is also big change from three-transistor to one-transistor cell. So I quickly followed one-transistor DRAM for coming 16-kilobit DRAM.

Fairbairn: Right.

Itoh: Fortunately, I could present my 16-kilo at ISSCC 1976. This is - I presented at ISSCC. This is first DRAM presented from Japan.

Fairbairn: I see.

Itoh: But - so the 16-kilo DRAM was first, world's first. It was presented from Hitachi, me and Intel. But unfortunately, my 16-kilo is for 22 pins package.

Fairbairn: Right.

Itoh: - while Intel is 16-pin, 16-pin package. Oh, so this is a big different. So after presenting my talk at ISSCC Philadelphia, I returned to Japan. So some claim was waiting for me, which is, "Why did you develop such a 22 package pin - pin package? You know, Intel 16 pins - of course, more, you know, attractive. Why? Why?" It is a very, very -

Fairbairn: Actually I thought that Intel also did a 22-pin package, that Mostek was the first one to, you know -

Itoh: No. It is - no. At first for 1-kilo, the 22 pin. But 4K and 16K they changed the 12 - no, 16 pin.

Fairbairn: Okay. So what were the - were the other Japanese companies pursuing DRAM with the -

Itoh: Of course. Almost all semiconductor companies were working on DRAM, of course. Because memory is just a good source for making money, you know.

Fairbairn: Right. And were you doing - did you have any cooperation with other Japanese companies? Or were you all completely doing by yourself?

Itoh: No. Only, Hitachi.

Fairbairn: Only Hitachi?

Itoh: Because there was very severe competition between Japanese semiconductor companies.

Fairbairn: Right.

Itoh: Independent.

Fairbairn: And was the Japanese government helping to fund some of the development in the semiconductor area?

Itoh: Yes. Looking back in 1970s there is big movement in Japan, which is we must go to semiconductor. So I understand that many funds were built. And the government-supported project was established in 1970s.

Fairbairn: So the 16K, did you redesign your 16K RAM for 16-pin package or do you…

Itoh: Yes. I changed the - my 16K bit to another 16. But it is - the another 16 feature, the very - features, which is power supply is only one, 5-volt.

Fairbairn: Oh.

Itoh: At that time, power supply, the standard power supply was 12V ~~.5~~ and, plus minus 5V, three power supplies.

Fairbairn: Right.

Itoh: While I challenged to change the only one 5-volt power supply. And it was eventually used for our large computers. But this was not mainstream globally. It is only domestic, only in Hitachi. After that, I moved to another - moved to 64K DRAM with - supported by government. But unfortunately it was two power supplies.

So eventually it failed to enter into the market, global market. So in total, I failed four times. But I couldn't - I couldn't be fired by top management. So I must continue to develop coming 64K which has - which using a single 5-volt power supply. And I introduced my own patent idea which is folded bit-line arrangement. It is a very famous idea in the world.

Fairbairn: Yes.

Itoh: So combining five - only single power supply of 5 volt and my patent, my - our 64 K was succeeded, which according to the *Fortune*, magazine *Fortune*, worldwide share, we got the share of 40% worldwide.

Fairbairn: Like it

Itoh: Yes. So -

Fairbairn: 40%?

Itoh: As many as 40%. So Hitachi got a lot of money, profit. So that is why I could continue my research on DRAM. If I failed the last - the 64K I must leave Hitachi to another company.

Fairbairn: So was your 64K, was that the first one to operate on five volts only?

Itoh: Yes. That is the first. Although it failed as a product, but we got a 5-volt technology ahead, ahead, you know. So I invented the folded bit-line arrangement patent, combination of 5-volt technology and my patent resulted in the big success for the next 64K DRAM generation.

Fairbairn: So obviously that was a very important development. Did the folded bit-line produce a device that was more reliable?

Itoh: Yes. I think this technology is just suitable for noise generation, - suppress noise generation. This is because if we switch our power supply from 12-volt to 5-volt, the signal-noise ratio of memory cells is drastically degraded. Because power supply is reduced from 12 to 5 volt, so resultantly, accordingly, the signal-to-noise ratio is very degraded. So we must add another technology which increases the signal-to-noise ratio. This is just folded bit-line arrangement.

Fairbairn:
How did other companies - since you were the first to develop?

Itoh: Yes. But, you know, at that time, in fact, I presented my 5-volt, 64K - for the first time in the world at ISSCC.

Fairbairn: Yes.

Itoh: But, other company failed to produce into the market, because they had somewhat- noise - signal-to-noise problem. Why? I applied new, you know, folded bit-line technology. So it is okay for our product. In this year we found that we are top runner of the race of 64K. it is a very, very drastic change which occurred in 1980.

Fairbairn: So you first incorporated the folded bit-line in the 64K, not in the 16K, is that correct?

Itoh: For 16K I used open bit-line arrangement which came from Intel, Mostek, TI. But for the next generation 64K, I abandoned the open bit-line arrangement which has poor signal-to-noise ratio. So I abandoned, I stopped to apply. So I used my own patent for 64K. This is the key to success. And believe it - and believe it or not, the folded bit-line arrangement came from my experience for magnetic memory.

Fairbairn: Oh.

Itoh: It is very interesting, you know?

Fairbairn: Yes. Very interesting.

Itoh: So during my development of magnetic memory I suffered from a lot of noise. So at that time I recognized that reducing noise to improve the signal-to-noise ratio is most important for memory design, all memory design. So by analogy I could invent folded bit-line approach. This is a - this is a very - this analogy.

Fairbairn: So how did the other companies who did not yet have the folded bit-line technology, how did they make their 64K DRAM?

Itoh: Yes. They used open bit-line. Because if they used open bit-line, it is a very safety for them. Because preceding generation, many company adapted open bit-line

approach. So it is natural to say that they intended to use historical open bit-line arrangement. But to develop 64K, 5-volt 64K open bit-line is not sufficient, is not suitable for 5-volt 64K operation.

Fairbairn: Right.

Itoh: So I - at that time I think developing 5-volt 64K is my last chance in Hitachi. Because I failed four times. So the 5-volt 64K development is a last chance to me in Hitachi. That is why -

Fairbairn: Right.

Itoh: - I decided to use my own patent.

Fairbairn: So what this other - you used the folded bit-line in the 64K -

Itoh: And - yes.

Fairbairn: - and the other companies - the other companies…

Itoh: You know, almost all other company used open bit-line arrangement. But they - I understand they suffered from poor signal-to-noise ratio. Then -

Fairbairn: Okay.

Itoh: Then at the next generation, I mean, 256K -

Fairbairn: Yes.

Itoh: All companies used the folded bit-line arrangement.

Fairbairn: I see.

Itoh: It is quickly followed by many competitors.

Fairbairn: Right.

Itoh: So folded bit-line invention is very historical in development history.

Fairbairn: So did all these companies have to license your technology to be able to use it?

Itoh: Yes. Unavoidably they must use folded bit-line.

Fairbairn: So starting in the 1980s, you say the 64K, when was that announced? What year was that product announced?

Itoh: Many - some competitors announced they could produce 64K product, but reality is not so. Many, many companies failed. So only one was a real top runner, according to the *Fortune*.

Fairbairn: When did you - when did you announce - when did Hitachi announce your 64K RAM?

Itoh: I think it is 1977 - no, 1979. At that time I went to - I visited many users in United States and Canada bringing my hot sample, several hot samples.

Fairbairn: Yes.

Itoh: So I understand that it is 1979 announced formally. And just after, I presented my achievement at ISSCC.

Fairbairn: I see. And I understand that in the 1980s Japan - Hitachi and other Japanese companies became very, very successful and even Intel withdrew from the memory market because -

Itoh: Yes.

Fairbairn: They could not compete.

Itoh: Yes. I understand.

Fairbairn: What were the - what were the major reasons why Japan was so successful even to the point of driving Intel out of the market?

Itoh: Yes. I think a combination of top management, strong top management and new technology, circuit technology and process technology. This combination is key to success I think. And yes, in fact, we were strongly supported by top management of Hitachi. Because semiconductor memory is just only one to get a profit, to get a money at that time. So I understand all Japanese semiconductor company rushed to the semiconductor memory.

Fairbairn: And one of the things that I remember in the 1980s was the yield that you were getting on your product, the number of good products was much larger than what U.S. companies were able to do.

Itoh: Yes.

Fairbairn: And in fact, I think, some U.S. companies didn't believe that you were being - that you were getting the yield that you did. Do you remember what kind of yields you had for 64K DRAM?

Itoh: It is almost top secret. But it is a very high yield.

Fairbairn: This is old - this is old information now.

Itoh: It is - and very, very big yield, yes, I think. And due to stable operation of chips, you know.

Fairbairn: So…

Itoh: Stable operation by using new technology. And safety design with wide margin.

Fairbairn: Oh, I see.

Itoh: which resulted in high yield.

Fairbairn: Did you work very closely with the manufacturing line? Do you…

Itoh: No. I am - I am circuit designer, but -

Fairbairn: Circuit designer.

Itoh: I substantially I was a project leader because there is no person who experienced the semiconductor memory. So I continued to be a substantially top technology leader.

Fairbairn: So other people worked with the manufacturing to -

Itoh: Yes, of course.

Fairbairn: get -

Itoh: Yes. To make memory chip profitable we need a lot of people, you know. Circuit designer and process designer, equipment designer and evaluation. There is many - we need many teams. I think we need, for example, “100 engineers for one product”.

Fairbairn: Right. And so you were very successful with the 64K DRAM -

Itoh: Yes.

Fairbairn: So you got to keep your job.

Itoh: Yes. Thanks to the success. Yes I could keep job. Yes. That is right.

Fairbairn: What were the major developments and challenges going to the 256K DRAM?

Itoh: 256K - a major contributor is scaled-down, you know, fine process technology. And 5-volt circuit technology and bit-line arrangement - for the bit-line arrangement continued to be used for - until 2000 - mid-2000. On - so, at 256K device, as a main contributor.

But next 1-mega generation, Hitachi proposed very interesting memory structure, which is three dimensional memory cells structure, stacked memory cell and trench capacitor memory cell, which was awarded by IEEE in 1996. Medal - we got a medal. So I think there is a big innovation was at 1 mega.

Fairbairn: At 1 megabit the trench capacitor became critical.

Itoh: But this is only for conference level. At first we presented one megabit using trench capacitor. But it is only for conference. Such a vertical memory cell was introduced at 4-megabit generation.

Fairbairn: Oh, I see. So the 1-megabit did not - the production version -

Itoh: No.

Fairbairn: Did not contain trench capacitor?

Itoh: And also - I must add something. For - at 1-megabit generation the very controversial issue was we have to introduce such a vertical capacitor cell and CMOS instead of traditional NMOS.

Fairbairn: Right.

Itoh: In fact, in 1980, at IEDM, we Hitachi proposed CMOS DRAM. But the CMOS technology was introduced into experimental1K, not product. So there is some gap, leading time.

Fairbairn: 1K? 1-megabit product?

Itoh: Yes, It was only for experimental chip...For 1 megabit product, ~~is just,~~ you know, reducing power dissipation is a very serious concern for DRAM users. So we had to change NMOS technology to CMOS. The transition actually occurred at 1-megabit product.

Fairbairn: Right.

Itoh: Yes.

Fairbairn: And, so did Hitachi continue to be successful at 256K and 1-megabit levels?

Itoh: Yes. And 4 mega.

Fairbairn: And 4 megabit?

Itoh: Yes.

Fairbairn: Did you - at that time when you were designing 256K and 1 megabit, did you have in your mind how far you could go? How bit a memory you could make?

Itoh: Every generation I felt that this generation is the last one. Because we were every time facing with utmost stress. We must incorporate the most advanced technology for the present generation. So we couldn't afford to think about the next generation is coming. We couldn't say so. Every generation, "Oh, this is our last generation."

Fairbairn: And, so then you did - you continued to be the lead designer for the 1-megabit and the 4-megabit?

Itoh: Yes. We have two teams. To keep up with rapid changing, we must make two team**s**, two teams in Hitachi Central Research Lab. And one is for production and another one is for, you know, research for the next generation.

Fairbairn: Right.

Itoh: Some - one or two years is overlapped.

Fairbairn: Yes. Because you always have to move very quickly.

Itoh: Yes.

Fairbairn: And so then, what happened at the 4-megabit level?

Itoh: Yes. Unfortunately - to be honest, 1-megabit - Toshiba got top share for 1-megabit generation. Because I understand that top management of Toshiba pushed the engineering group. And so, thanks to such a pressure from top, Toshiba gains number one share at 1-megabit generation. But next generation 4-megabit, Hitachi again got the top share. It is very interesting. There was a very severe competition in Japan.

Fairbairn: Very competitive. Yes.

Itoh: Yes.

Fairbairn: So what happened - what was the major challenge or new development at the 4-megabit level? You were using CMOS…

Itoh: Yes, of course, CMOS, and which types of 3D capacitor is better. I mean, we, Hitachi proposed stacked capacity and trench capacitor. But which capacitor is better for the product? This was very annoying to me. Although we invented two types of

memory cell structures. But finally, we adapted stacked capacitor memory cell for 4-megabit and eventually we were the top runner of 4-megabit ~~gigabit~~ race.

Fairbairn: So what happened - then Hitachi got to 4-megabit and had the lead market share -

Itoh: Yes.

Fairbairn: - in 4-megabit.

Itoh: Yes.

Fairbairn: And then you moved to 16-megabit.

Itoh:16-meg and the 64-meg. And after 64-meg there is a very famous story. We announced a new type of 64-megabit at VLSI Circuit Symposium, which, one of the features is 1.5-volt battery operation DRAM. At that time 5-volt is standard, 5-volt operation DRAM is the de facto standard.

Fairbairn: Right.

Itoh: At that time I changed, drastically changed 5-volt to 1.5 volt suitable for battery operation. So I understand after that low power activity with low-voltage operations became strong in the world. I think, this 1.5-volt 64-meg was just a trigger for development of all the low-power LSIs thereafter.

Fairbairn: Yes.

Itoh: So you can see some special portal. The biggest development in 1990 was our 64-meg. You can see such an article at *IEEE Spectrum in January, 1991*. So such a drastic change from 5-volt to 1.5 volt, it is very, very historical in the LSI technology development, I think.

So anyway, I could continue 64-meg - 16-meg and 64-meg. After that I switched my research to low voltage circuit technology apart from DRAM development.

Fairbairn: I want to talk about that, but before we do was - did Hitachi continue to be successful in the market with the 16 and 64 megabit DRAM.

Itoh: Yes, I think so in terms of technology. But meantime, you know, Korea, Samsung became stronger. So market share is not decided only by technology, but, I think, decision of, you know, investment of top management.

Fairbairn: Right.

Itoh: This is closely related to each other.

Fairbairn: Right.

Itoh: I understand although we are the top runner of technology development, it doesn't mean success in the market. A key to success is a top decision, global top decision, including big and timely investment, you know.

Fairbairn: So did Samsung become a leader in DRAM at the 256-megabit level?

Itoh: Yes. I understand so.

Fairbairn: So you switched your focus on research to low power technology.

Itoh: Yes, I proposed a lot of new circuit technology to reduce leakage current. In fact, I started - I started such a technology in 1980 - as early as 1988.

Fairbairn: Oh.

Itoh: After my proposals it took about 10 years until many semiconductor companies actually use my proposals.

Fairbairn: Did you take 10 years?

Itoh: Yes.

Fairbairn: And…

Itoh: I can't say what company uses this one.

Fairbairn: So can you talk about what those major developments were? What were the key things? You talked about reducing leakage current.

Itoh: Yes.

Fairbairn: And is that related to the FinFET transistor or…

Itoh: No, independent. It is useful circuit for all LSIs, for all low-power LSIs. It is very useful.

Fairbairn: Okay.

Itoh: You can see my - in my biography and my article. It is a true story.

Fairbairn: Okay.

Itoh: Yes.

Fairbairn: And what products, if you were no longer working on DRAM, what types of products were you focused on for low power? Was it microprocessors or other - what kind of products?

Itoh: I understand the Hitachi DRAM activity moved to Elpida. Static DRAM activity moved to Renesas and then to Elpida.

Fairbairn: Right.

Itoh: and then Micron.

Fairbairn: Right. But what products did you apply your ideas for low-power technology…

Itoh: I understand this is for multi-gigabit-DRAMs.

Fairbairn: Okay.

Itoh: - and it is also for SoCs and MPUs.

Fairbairn: Right. So you were primarily focused on research for - fundamental research for reducing leakage current, and other people then applied some of your ideas to DRAM and to microprocessors and other devices.

Itoh: Yes.

Fairbairn: Is that correct?

Itoh: I understand they may use unconsciously, without recognizing about my many ideas for reducing leakage current that I presented at major conferences. Unfortunately, however, my inventions are too early to come, so some of them have expired.

Fairbairn: So can you tell me about any - any more about your further research in low power? What kinds of things, besides leakage current were you pursuing?

Itoh: I am sorry, what…

Fairbairn: Let me - let me ask again.

Itoh: Yes.

Fairbairn: You said one of your major contributions was in reducing leakage current. What other - what other ideas or techniques did you develop to help design low power products?

Itoh: Yes. I understand that major technique, circuit technique is how to reduce leakage current. By using special circuit technique, as well as new devices like, you know, high-k metal gate and SOI MOSFETs. But I understand that circuit contributions is the biggest, I think.

Fairbairn: Okay.

Itoh: So combination of circuit technique and process and device, you know -

Fairbairn: Yes.

Itoh: is exemplified by SOI, high-k and SOI.

Fairbairn: Right. So did you do further work in semiconductor circuit design beyond what you have described? Are there other things that you were - are there other things that you were involved in that we haven't talked about yet?

Itoh: Yes. I have many things, I send my message to young people. I have many, many things to - for giving some message to young people. So you can see my thought in my articles, biography and *IEEE SSCS magazine*, you can find more - in more detail. And also I wrote a Japanese book entitled R&D Story of a Fanatic Researcher.

Fairbairn: Right. And right now that book is only in Japanese, is that correct?

Itoh: Only Japanese.

Fairbairn: Right.

Itoh: But it is just not on sale. This is only inside Hitachi for foster young people.

Fairbairn: Oh, right. Is it possible for us to get a copy of it?

Itoh: Yes, of course.

Fairbairn: Okay. That would be great. We would like to add it to our collection. We want to - You know, we want to collect all the information we can about the development of these important technologies -

Itoh: Yes.

Fairbairn: and even if it is in Japanese, there will be people that can use it for research.

Itoh: Yes.

Fairbairn: And so we would be delighted to have it.

Itoh: Thank you.

Fairbairn: So do you think that there is significant progress still to be made in terms of lowering power?

Itoh: I am - yes, in fact, I think despite many prosperous applications, I feel that the number of real innovative technologies has declined. So I am eager to see drastic cost reduction and low power memory. So, at present, I am now pursuing such other low-power memory, still pursuing.

Fairbairn: Oh. So you are still working?

Itoh: Yes, of course. Yes. In my life I am engineer, you know, researcher. This is just a job satisfaction as you…

Fairbairn: And will this ultra-low power technology use - on something that is in silicon? Will it use…

Itoh: Yes, of course, silicon. Combination of silicon.

Fairbairn: Right.

Itoh: Of course, this is a very - very useful for IoT era, as well as medical application. So I think, at present, I think, ultra-low power.

Fairbairn: And what voltage do you - how low a voltage do you think you can reach?

Itoh: I am sorry, I can't say about it.

Fairbairn: You can't say.

Itoh: That is some secret, you know. I am sorry. Ultra-low voltage.

Fairbairn: Ultra-low voltage.

Itoh: How ultra - I can't say about it because it is a very big…

Fairbairn: But still - but still with silicon transistors?

Itoh: Of course.

Fairbairn: Right. Not silicon on insulator?

Itoh: Silicon.

Fairbairn: Silicon on insulator?

Itoh: Yes, of course. CMOS, conventional CMOS.

Fairbairn: Conventional CMOS.

Itoh: Yes. So by using some technique, circuit technique -

Fairbairn: Okay.

Itoh: We are now pursuing ultra-low voltage and low-power.

Fairbairn: Very interesting. So many new developments - many new developments yet to come.

Itoh: Yes. You can see my - our result in the coming major international conference.

Fairbairn: Yes. Is there - is there anything else you would like to say to conclude our discussion?

Itoh: Looking back, you know, the global and the leading top management need to respond quickly to rapidly changing semiconductor industry. It is key for the future. I am researcher. So even though I invented a lot of patents, and I would like to use them worldwide, it depends on the, for example, investment and so on, which is independent of technology. So I understand such a strong top leadership combined with ceaseless and timely technology development is a key to success in the future, I think.

Fairbairn: So it will require significant investment.

Itoh: Yes.

Fairbairn: Okay. Well, thank you very much for spending the time with us. And I learned a lot and I am sure -

Itoh: Thank you, I enjoyed.

Fairbairn: Future listeners will also be delighted to have your story told in this way. So thank you very much.

Itoh: Thank you very much. Thank you.

END OF THE INTERVIEW

