Oral History of Toshiaki Masuhara

Interviewed by:
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Douglas Fairbairn: Well, good morning.

Toshiaki Masuhara: Good morning.

Fairbairn: We are in the new Otani Hotel in Tokyo Japan. It is June 21, 2016 and I'm Doug Fairbairn. I'm here to interview Toshiaki Masuhara who has joined us and is going to tell us about his very rich and creative career in the world of electronics and low power devices. Welcome. Thank you for joining us.

Masuhara: Good to see you.

Fairbairn: We'll spend most of our time talking about your career activities. But we also like to start at the beginning: where you were born, what kind of family you grew up in, did your parents have an influence on your choice of direction in electronics, and that sort of thing. So, if you could, just give us a brief description of when and where you were born and a little bit about your own family life.

Masuhara: Well, I was born in Toyonaka City, Osaka prefecture in 1945. And I mostly lived in Kansai area, west part of Japan, and I spent several years in Osaka, but I don't have any memory of Osaka area. And I then moved to Kobe.

Fairbairn: Kansai, is that a rural area or a city?

Masuhara: Yes, Kansai is area, the name of the area including Osaka, Kyoto, Kobe. And I moved to-- my house moved to Amagasaki City and I went to the elementary school in Amagasaki and Ashiya. And then my family moved to Kokura, Kyushu, now it's called Kitakyushu City, North Kyushu city.

Fairbairn: So what was your father's career? Did you have to move because of his career?

Masuhara: My father has been working for Asahi Glass Company. He was in the sales area. So he has to move to several places in Japan.

Fairbairn: I see.

Masuhara: So I have to accompany him. So, I entered the junior high school in Kyushu and, in two years, my family moved to Nagoya. So I had to move to junior high school in Nagoya and I entered the senior high school in Nagoya.

Fairbairn: Was it difficult for you to keep moving all the time and lose friends?

Masuhara: Not difficult. I could deal, manage anyway.

Fairbairn: Did you have brothers and sisters?

Masuhara: Only one brother.

Fairbairn: Did he pursue a technical career or is he in some other...

Masuhara: He had a doctoral degree in Climate--.

Fairbairn: Climate, so meteorology and...

Masuhara: Meteorology, that's right. But he's currently teaching to young people.

Fairbairn: Did your parents encourage you to go to university and pursue a higher education?

Masuhara: No, mostly, I'm interested in doing technical things and they let me do what I wanted to do. So I didn't have any influence from my parents.

Fairbairn: Did you engage in any hobbies in electronics or anything when you were young?

Masuhara: Yes, when I was going to elementary school, I made a single stone radio and...

Fairbairn: Single crystal?

Masuhara: Single crystal radio, that's right. And then, at the sixth grade of elementary school, I purchased a transistor radio kit from Sony I think. And that was my first experience to fabricate that kind of things.

Fairbairn: So you then-- were there any teachers during your high school time that influenced you or that encouraged you?

Masuhara: Well, in high school, in Japan, we have a kind of a supervising teacher. At the first grade of my senior high school, my teacher was teaching chemistry and, in the second grade, my teacher was teaching physics. So I think I had some influence from them.

Fairbairn: Okay, so then you always wanted to go to university? That was something that was important to you?

Masuhara: Yes. When I had to choose what university and what specialty to be engaged in, I was choosing the electrical engineer at the Kyoto University.

Fairbairn: Is Kyoto University specialized in technology or does it have a broad range of offerings?

Masuhara: It has everything, just a university. So I had some influence from other people as well because, when I entered the university, I have chosen the glider club. At that time, Japan was very poor, so we didn't have a very good glider. But we did have a soarer-class glider. So I had to go to several places in Japan to do test flight.

Fairbairn: So your actual glider for gliding...

Masuhara: Yes.

Fairbairn: Was it towed up?

Masuhara: Yes, at that time, we used, for instance, the Cadillac automobile.

Fairbairn: To tow it?

Masuhara: Yes, because Japanese automobiles did not have a power...

Fairbairn: Powerful...

Masuhara: Not powerful enough, so either Cadillac automobile or winch roll on the tracks.

Fairbairn: So you would drive it down a runway and the glider would...

Masuhara: So what was done was they had a wire, steel wire, and the driver drives the car, and. the glider takes off. At the height of 300 meter we release the wire.

Fairbairn: Cut the-- right.

Masuhara: And the glider usually goes back to the original place. It was a very short flight.

Fairbairn: So you were piloting-- you were flying the glider?

Masuhara: Yes, I had the license at that time but not the high-level license. So that gave me influence from people in other engineering area...

Fairbairn: So were you doing this during your university time?

Masuhara: Yes. That means I had to get some money to glide and also it means you had to leave the classes. Japanese university was very free at that time. So I could ask somebody to get a note and I ask him to copy the notes.

Fairbairn: And you would go fly the glider.

Masuhara: Yes, that's right.

Fairbairn: So was that a hobby? Was that something you did for fun or was it some university work also?

Masuhara: Yes, so the experience of the glider gives you a lot. For instance, you have to know the mechanism of the glider and you also have to know the automobiles. And Cadillac, that Cadillac was very old so it failed very frequently.

Fairbairn: So then you had to fix it.

Masuhara: So somebody had to fix it. I remember when I was young I made the electric ignition because I heard it was very powerful. So I made the electric ignition by using the power transistor made in the United States, and ran a car on the usual road and it failed. It ran only hundred meters or so. It was not allowed now, I think.

Fairbairn: Interesting. So you studied electrical engineering and you got a bachelor's degree, a master's degree? What?

Masuhara: Yes.

Fairbairn: Did you continue straight through to get a PhD or...

Masuhara: No, in Japanese university, it was allowed to submit thesis, even though you were working in the company. So I finished the master's degree in electrical engineering and then entered Hitachi.

Fairbairn: Okay. What year did you enter the university?

Masuhara: I entered the Kyoto University in 1967.

Fairbairn: '67.

Masuhara: And I stayed four years undergraduate and then two years for master.

Fairbairn: Okay, so in 1974/1975, you left to go to...

Masuhara: No, it was 1969. Oh, just a moment. I was wrong. 1967 was the year that I entered master degree program.

Fairbairn: Master's program, yeah.

Masuhara: I started the master's program in 1967 and I finished the master program in 1969. I entered the university in 1963.

Fairbairn: So, in 1969, you then went to Hitachi Central Research Laboratory.

Masuhara: That's right.

Fairbairn: Why did you choose Hitachi?

Masuhara: I visited several companies in Japan: NEC, Sony, Fujitsu, and among them I liked the Central Research Lab of Hitachi most. Because it had a very good circumstances and it had a very wide area of technology.

Fairbairn: So you entered in 197...

Masuhara: ‘69.

Fairbairn: ...‘69. So what was the status of semiconductor technology within Hitachi at that time? What kind of technology were they using and did they-- was there a lot of research focused on semiconductors? Did you understand the important-- did the company understand the critical importance of semiconductor technology for the future?

Masuhara: Yes, at that time, I think Hitachi was one of the top companies manufacturing transistors. And they were beginning to manufacture the integrated circuits. They were working on the bipolar transistor IC’s for mainframes. And I remember, when I enter the company, that was the beginning time of the MOS integrated circuits. Doctor Kubo, who is my elder colleague, was beginning to design the p-channel MOS integrated circuits, working at the voltage of 12 volts or so. So I began working on the n-channel MOS integrated circuit that works at five volts. That was my first time to begin working on integrated circuits.

Fairbairn: Was that your first job coming into the research laboratory, was on n-channel...

Masuhara: Yes. At that time, Dr. Tokuyama had developed the LTP transistor. That was-- I don’t know the abbreviation that was a...

Fairbairn: Low Temperature Passivated?

Masuhara: Low Temperature Passivated, that’s right. That’s right. That was for very low-noise transistor. And he did chemical vapor deposition on top of the junction and his research unit had the technology to apply that passivation to MOS transistors. They’re working on aluminum oxide. So I went to his office and did the chemical vapor deposition and made the first n-channel MOS circuit at Central Research Lab.

Fairbairn: Very important development.

Masuhara: Yes, that’s right. But it failed as I have written in this article.

Fairbairn: Very important development. When you came out of the university, did you have any particular interest or you were happy to work in any of the areas that they required work?

Masuhara: Well, I didn't tell you. When I was in the university in the master's degree, Professor Sasaki was my supervisor. And, at that time, as you know, in 1963, Dr. Gunn developed, so-called Gunn diode. That's a gallium arsenide diode and Prof. Sasaki was trying to do some research in that. So I did some research by using gallium arsenide. I was involved in measuring the high-field domain that was generated in the Gunn diode in the university. And I remember when I was doing that research, my professor Sasaki purchased one gram of the gallium arsenide from Monsanto.

Fairbairn: One gram?

Masuhara: Yes one gram. That cost was 300,000 yen. So I used that one gram throughout my research. Very,...

Fairbairn: Very carefully.

Masuhara: Yes it was very precious semiconductor. But I found that silicon, when I first entered the company, I found silicon is much easier to handle. So I realized there is no future for the gallium arsenide and I changed my mind into silicon circuits.

Fairbairn: Did you originally-- were people originally looking at gallium arsenide because they thought it had higher performance…higher mobility? Was that the reason?

Masuhara: Yes, higher performance. They have negative conductance. As you know, there was Esaki diode which has the current/voltage relationship, which increases first and then decreases. And the gallium arsenide has that kind of structure, physically, so that it creates the so-called high-field domain inside the semiconductor and people were trying to use that high-field domain for several purposes, microwave oscillators or for some functional devices. So I thought, when I was in the university, functional device was the way to go. But I found silicon is much better way to go.

Fairbairn: So you began work. Did you ever do any work in germanium? Is that all passed by the time you...

Masuhara: Germanium transistor-- yes, I made the transistor radio by using that kind of things. Actually, my electric ignition was made by using geranium. That's why it was not so stable.

Fairbairn: So you're then describing the initial work that you did at Hitachi. Please proceed with that. What was the result of that initial investigation that you did?

Masuhara: Oh, in 1971, I had a paper at ISSCC. I think that was probably the first or second paper for ISSCC from Hitachi.

Fairbairn: You were very young.

Masuhara: Yes. The integrated circuit was a 2K read-only memory working at five volts by using five-volt single supply, TTL-compatible. So that was the first TTL-compatible five-volt single supply memory in the world. So, in that sense, that was successful. But people...

Fairbairn: Was that a metal gate process?

Masuhara: Metal gate process and dual oxide of the aluminum oxide and the silicon dioxide for the enhancement mode device, and silicon dioxide for depletion mode device. It was an enhancement and depletion mode circuit. That's why it could be operated at five volts. But, since it was using aluminum oxide, when My supervisor, Dr. Nagata, and myself decided to make it real products and worked for two or three years, I think, it was not successful because there were inherent instabilities existed in between aluminum oxide and silicon dioxide interface. So the threshold voltage changed in time. So we had that kind of a problem. So people in Hitachi decided not to use that for actual product purposes. Instead, they decided to use ion-implantation to control the threshold voltage for n-channel MOS.

Fairbairn: So did you-- in the research laboratory, was your goal mainly to do basic research? You said you got involved in trying to develop products. So did the research lab also work in product development at times?

Masuhara: I was trying to make real products. But, after that project failed, I became a kind of internally fired researcher. So there was no job for me. So, I decided to work on some fundamental area. Since I was working on the low voltage circuits, I found the MOS transistor did not ideally, turns on and off. There was some region called sub-threshold region. There was the region, in which the current changed exponentially with the gate voltage. So I decided to analyze that and I proposed a model of the MOS transistor. Around that time, there were some analyses on the sub-threshold characteristics of MOS transistor. But there was no MOS transistor, entire region model. So I developed a model and analyzed the circuits. I submitted a paper to Transaction on Electron Devices, IEEE in 1974.

Fairbairn: So did you have any-- at that time, there was no simulation software. Did you code the model in computer model or was it...

Masuhara: Yes, at that time, I think, Hitachi had some contracts between us and Rockwell I think. And there was a simulator called SYSCAP. And Hitachi did have an internal simulator called HiCAD. So we have been using these kinds of simulators for the circuit analysis but...

Fairbairn: So, did you build your new model into that simulator?

Masuhara: No, I just did my analysis with it.

Fairbairn: Hand calculation, yeah.

Masuhara: That was for doing some work. I did analyze the inverter circuits but that was all. So it was kind of separate, since I was working as a single fired researcher.

Fairbairn: Well, analyzing the sub-threshold currents was very important at that time, correct? If it was not well understood...

Masuhara: Nobody realized that sub-threshold was important because the circuit was operated five volts or more. Sub-threshold was not important. But recently everybody concerned about sub-threshold characteristics in the MOS transistor

Fairbairn: So, after you did the 2K ROM example, what was your next project?

Masuhara: Well, as a matter of fact, I went to University of California, Berkeley in the year 1974, because I got scholarship from Hitachi to study a year. So I went to University of California, Berkeley and worked with Professor Richard Muller. He became famous for the MEMS project recently.

Fairbairn: Oh, wow.

Masuhara: But at that time, he was working on MOS transistor analysis. So I went to his lab and actually I stayed in his research Lab. I went to the University of California, Berkeley, I think in September of 1974, and I stayed until the summer of 1975. So, during that year, I worked first on the analysis of the DMOS transistor, double-diffused MOS transistor, and then I applied that technology to develop, so-called double-diffused CMOS. I submitted two papers to conferences. And I actually manufactured the device, CMOS device in University of California. I think that was the first CMOS in University of California, Berkeley.

Fairbairn: Tell me more about your experience at Berkeley, just in terms of your personal experience and what things you learned. First, how did you see that the U.S. university differed or was different from a Japanese university?

Masuhara: Well, first of all, when I first entered the University of California, since my English was not good, I had to attend the English course. And, at the same time, I took three courses because I was a special student. And I took three courses every quarter and that means, as you know, like Stanford, if you take one course, you have to study eight hours or so a week to do the homework. And that was my good experience, good and hard experience. Since I was working for the lab, I was doing some experiment in the lab - and I have to take three courses. That was quite an experience.

Fairbairn: You were very busy.

Masuhara: Yes. Fortunately, I was single at that time, even though I was married. Since my wife had a baby in September, she stayed in Japan. After she had the baby, she came to United States in December. So, during September to December, I was single. I stayed in International House. So I had some international friends there as well. I still have some intimate relationship with them. So it was good experience, study and to get international friends, and doing research.

Fairbairn: Was the way the classes were run were different than how it’s done in Japan?

Masuhara: Quite different. First of all, you got a lot of homework and I realized that you also had a term paper, term project or things like that. I still remember that was winter quarter, I think in Professor Paul Gray’s course, that was EECS 241, he did a lot of analysis of the operation amplifier, and he also required us to do some revision of the circuit for the existing amplifier circuit. For instance, I still remember first term project of the Professor Gray was on so-called, uA741 amplifier, which was a very famous amplifier, to increase the common mode range of that amplifier. So a lot of people created their own circuits and did their analysis by using SPICE. So I had to do a lot of analysis by using SPICE. At that time, there was a batch system. So the batch system computer was very crowded during daytime. I usually worked at night. I went back to my home, five o’clock in the morning or so. It was quite an experience. That kind of experience, can’t happen in the University in Japan.

Fairbairn: You also made many friends and associates while you were there.

Masuhara: Yes, mostly-- for instance, my best friends were mostly made on the tennis court rather than the classroom. So I still have an intimate relationship with them. I exchange Christmas cards and I exchange e-mails. One of my friends, live in Saratoga at the top of a hill. I once visited my friends in Saratoga. He was one of my best 10 friends. His name is Paul Suciu. He came from Romania. I also have a lot of international friends in Germany, for instance Fred Hosticka who came from Czechoslovakia after the Russian troops came to Czechoslovakia.

Fairbairn: He left.

Masuhara: Yes. And he still lives in Germany right now. So those experiences were interesting to me.

Fairbairn: So you came back to Hitachi after one year. Did that experience in the U.S. change your interest or focus your interest in a new area?

Masuhara: Yes. As I told you, I was very keen on developing real products. And, since I worked on CMOS in Berkeley as I have told you, when I was in Berkeley, nobody regarded CMOS was the way to go. At that time, CMOS was regarded as a very slow product, just for watches and calculators. I found CMOS is very good in terms of the low power, but very slow and very complex process. If you cope with those two problems, you can make very competitive products. So I decided to work on CMOS in Hitachi. At that time, there was a big project to work in Hitachi to develop NMOS following the IBM mainframe computer. So they were very keen on developing NMOS two-micron processor. So I decided to work on CMOS circuits. And since there was no process in Central Research Lab on CMOS, I decided to use the CMOS process in Musashi works, because they were manufacturing five-micron CMOS for the calculators and watches. I first made, as I have written in this article,. my first project was to develop analog MOS circuits by using 5-micron CMOS process. So the name of the test-element-group (TEG) was called Advanced Analog MOS or "ADAM".

Fairbairn: So ADAM, A-D-A-M?

Masuhara: That's right.

Fairbairn: And Mr. Sakai joined my project and he proposed a very interesting structure of the CMOS that's called double-well or twin-well CMOS. As you know, at that time, the CMOS was using the single well. Actually, CMOS is the transistor. Here let me explain a little bit by using figures for technical things, because I have an article. CMOS actually is made by using two kinds of transistors, pMOS transistors, and nMOS transistors. And at that time, usually, nMOS transistors were made in the P well. The P well is made on the substrate, an N substrate. So that means p-type doping should have higher doping level,at that time doping level of 10^{16} cm $^{-3}$ or something. If you can use very low-doped P well, you can increase the speed. So Sakai-san developed the process to use two types of wells in very lightly-doped substrate. He called it double-well. But it was later called twin-well. He developed a process and we decided to work on three micron CMOS process. First I designed DMOS, excuse me, DRAM circuits by using that because DRAM was the kind of rice for the semiconductor industry at that time. But I found to develop DRAM, it has a very heavy inertia. It is very fatal if you fail the development. And--

Fairbairn: It's very sensitive. You have to..

Masuhara: Sensitive, yes. So it was not a good vehicle to develop CMOS process, so I decided to work on SRAM.

Fairbairn: When you started on the CMOS work, did you have trouble convincing people to have you do this, since there was so much attention on nMOS? Or did Hitachi comfortable with you proceeding on the CMOS?

Masuhara: As a matter a fact, I had a very good friend in Musashi works, semiconductor division. His name is Mr. Yasui. And he had been developing the CMOS SRAM by using polysilicon-load SRAM cell. As you know, SRAM cell is a kind of flip-flop, six transistor flip-flop. In CMOS, usually you use CMOS inverter with PMOS load transistor. But he was using the polysilicon-load, very high resistivity polysilicon. And his development was not going very well. And, actually, he was my colleague when I was at University of Kyoto. Right next to my research lab, he was doing some research. So we had a lot of experience.

Fairbairn: So you knew each other well.

Masuhara: Actually, I helped him in writing his Master's degree thesis.

Fairbairn: Thesis...

Masuhara: ... By the way, since he was a very good friend, we had frequent discussion. And since he said he was developing the polysilicon-load CMOS cell that wasn't going well, and since I'm working in the Central Research Lab, working on the CMOS circuit by using twin-type well, why don't we combine those together? So we decided to make a joint project. So it was-- he and me who decided to create the project. I didn't have to persuade anybody. Only thing I had to do was to persuade my supervisor, Dr. Kubo.

Fairbairn: Those personal connections are very important.

Masuhara: That's right. But at that time of silicon technology stage, I was lucky enough because you didn't need a lot of money to create a project. So that was beginning of the project.

Fairbairn: So you went on to develop a very successful CMOS static RAM.

Masuhara: Mr. Yasui and I decided to develop the 4K CMOS SRAM. At that time, Intel was the top manufacturer of the high speed SRAM. And the part name was Intel 2147. We decided to develop CMOS SRAM, which was as fast as the Intel nMOS SRAM 2147 and has much less power and much less die area. Since we were using nMOS type polysilicon-load cell for the SRAM cell, the area was very small. They were contained in a single well. And we were using CMOS peripheral, so the power was much lower. I remember it was the year of 1977, we designed the circuit and we manufactured the device at Musashi works by using three-micron process. And we submitted the paper to ISSCC and that was accepted and we had the first paper in 1978. That was made into a project, actually a product later named 6147.

Fairbairn: So you had a very successful product.

Masuhara: Yes, I think that was successful in terms to surprise people in the world. Not economically successful. Economically successful product was the next one. That was 6116. That was 16K.

Fairbairn: Is that a 16K?

Masuhara: ...16k SRAM, 2k by 8.

Fairbairn: So when you developed this 4K and Hitachi saw the result, did they then form a special group, a dedicated group to build these CMOS SRAMS?

Masuhara: Yes, we created a group of people. It was kind of a joint project between Hitachi Central Research and Hitachi Musashi works in semiconductor division. And, actually, there was special project called Tokken, which means "special project," company-wide special project. And in that project we developed, I think, the 4K SRAM and the 16K SRAM. So that worked very well. I think you had some interview to Dr. Makimoto of Hitachi several years ago and he talked about that project, how successful was that project.

Fairbairn: So what was the next step after you had developed this very successful static RAM demonstration?

Masuhara: Yes, let's see. In the Central Research, I was the supervisor of the research-unit for ten years, I think. During that time, a group of people working for me developed an imager device. That was the first solid state imager. And then..

Fairbairn: What was the application for that or what was the business that Hitachi was interested to procure the image?

Masuhara: Actually, they made television cameras using that solid-state imager. And later, CCD has become more popular. But first solid-state camera was the MOS imager made by Hitachi. And then CCD exchanged the MOS imager. Then CCD was exchanged by the CMOS imager recently.

Fairbairn: Does Hitachi continue to develop imaging?

Masuhara: We provided the imager chips to some other companies. But during competition, Hitachi failed to win CCD by the MOS imager. So, CCD groups won the second stage, for instance, Sony, and then maybe NEC or Toshiba. Sony still is the top manufacturer of the CMOS imager. So it changes, anyway. But I'm happy to say Hitachi was the first supplier of the solid-state imager. It was actually not my group but was Dr.Kubo's group that developed the first MOS imager. And then at the last stage of my supervising stage, we developed a DRAM. Hitachi actually developed a 1 Mb DRAM, but failed to be the top supplier. At that time, Toshiba had become the top supplier of DRAM. So it was a company-wide problem to win Toshiba. So the general manager of Central Research appointed me to become supervisor to develop the 4 Mb DRAM in the Central Research. Actually, we had a joint project, company-wide project later. That was, I think, governed by Dr. Makimoto. And..

Fairbairn: So the 4 Mb DRAM, that was very important and essential product that..

Masuhara: Yes, that's right. Actually, we had got top status in the 4Mb DRAM in the world.

Fairbairn: So did you get the top position, because you were able to get out early? You had focused on that and got a product out early. Is there some unique things about the product that made it superior? What was the key to becoming the top supplier for the 4 megabit? Was it mainly time of technology or..?

Masuhara: It's a good question. I think at that time we had organization called Device Development Center, which was jointly supported by semiconductor division of Hitachi, communication division and computer division. All of the three divisions provided some money to keep that organization. So the Device Development Center has been developing circuits for the mainframe computer, for instance. And also they did some development for the DRAM. That was one of the reasons I didn't choose DRAM for the first time to develop the CMOS process. Instead, I chose SRAM so that we don't have to compete with Device Development Center. But I thought at that time joint development between all of those groups is very important. So we established a group in the Device Development Center. And people got together in that area. So we, and I actually went to Device Development Center to develop 4 Mb DRAM, and people from Musashi works came there as well. So it was a kind of very big project. I also included 1 Mb SRAM. So we jointly developed 1 Mb SRAM and 4Mb DRAM in the same project.

Fairbairn: Same process?

Masuhara: In the same project, not in the same-- but in the same CMOS process. So the DRAM was manufactured by using stacked-capacitor cell. That was the first three-dimensional stacked capacitor cell DRAM in the world, I think.

Fairbairn: That made for a very small bit size.

Masuhara: Yes. At that time Toshiba and IBM had been working on the trench-capacitor cell. And we also developed trench-capacitor for the 1 Mb DRAM in Hitachi. But I thought the trench-capacitor cell was not good in terms of the stability against alpha particle soft errors. And so we have chosen stacked-capacitor cell for this project.

Fairbairn: So also, to be successful in DRAM, you also have to have a big factory. Did you build a new factory to manufacture the 4 Mb?

Masuhara: Yes, I think semiconductor division manufactured the product, I think in the Kofu Factory, which is west of Tokyo. We had a factory there. Not a big factory. It was not a 300mm era.

Fairbairn: Approximately what minimum line width was the 4 MB developed in?

Masuhara: 4 Mb DRAM was, I think, manufactured by 0.8 micron CMOS.

Fairbairn: Did you have to develop the whole chip or is your major focus on developing the cell or what was your group responsible for? The whole project?

Masuhara: In that project they made a whole chip. And since semiconductor division is involved in, they made the whole product.

Fairbairn: Over what period of time, what years were you working on that 4 megabit DRAM?

Masuhara: 4 Mb DRAM. I remember it was the year in between, '85 to '88, '87 or so.

Fairbairn: So then what was the next step in your career move?

Masuhara: I become the department manager of the Seventh Department in the Central Research. At that time, we have been working on many kinds of devices in the Seventh Department, for instance, DRAM, SRAM, processors for mainframes, DSPs, analog digital LSI, things like that, all kinds of integrated circuit designs. I was in the Seventh Department for three years or so. And then I was assigned another job in the First Department in the Central Research, just for a year. And I had another job in Telecommunications Division for one and half a year. So I had many experiences in management.

Fairbairn: You were developing new devices in those groups or mainly focused on manufacturing? Or what was the...?

Masuhara: Developing mostly, except in the First Department. In the First Department, I was doing very fundamental development, quantum devices, things like that. So, my next step?

Fairbairn: Yeah, tell me the next step.

Masuhara: I was asked to go back to Semiconductor Division and I become the General Manager on the technology in the Semiconductor Division. So I was in charge of the general technology, for instance, process, packaging and design automation. At that time Hitachi has been working in many kinds of technologies.

Fairbairn: Was there any particular project or technology in that area that was your major focus or an area where you really felt it was critical for Hitachi to make significant advance?

Masuhara: At that time, I think still DRAM was the major project. So we have to be successful anyway to develop next generation DRAM. But at that time we had some trade friction in between Japan and the United States. Trade friction didn't affect the technology, but at that time, I think, technology has been expanding. For instance, the investment has become very high, for instance. So Hitachi had to manufacture DRAM in Korea, for instance. So manufacturing people had to go to Korea very frequently, design and the product people also had to go to Korea very frequently.

Fairbairn: You did that in Korea to lower the cost?

Masuhara: Well, in a part yes. I was not in charge of the technology outside, but I was in charge of technology inside, inside semiconductor division. So I had to go to, for instance, Takasaki works, which is one of the factories in semiconductor division specializing in analog integrated circuits. At that time, people werevworking in developing analog-digital mixed-signal integrated circuits for VCR camcorder or VCR tape recorder. So those were the main products as well for Hitachi. So Hitachi has been working in many areas.

Fairbairn: But Hitachi was setting up manufacturing lines in Korea?

Masuhara: Only for DRAM.

Fairbairn: And why did they do that in Korea versus Japan or somewhere else?

Masuhara: Simply because Korean people wanted to manufacture device, invest some money in the device, maybe.

Fairbairn: So they were willing to do the investment.

Masuhara: Yes, to get the technology. So NEC has been working with Samsung, probably. And Hitachi has been working with Lucky Gold Star-- LG semiconductor.

Fairbairn: So they were most interested in getting the technology.

Masuhara: So the reason for Hitachi was to save some money. You get some capacity from Korea.

Fairbairn: Right, right. It was becoming very expensive to build new factories for DRAM.

Masuhara: Hitachi also tried to build process for DRAM in Naka works, which was-- Hitachi has many heavy industry manufacturing sites, I should say. So they, Hitachi tried to modify those sites to semiconductor facilities. But the investment was very high, very heavy for Hitachi. So they started to use fabs other than Hitachi.

Fairbairn: I see. I see. Okay, so then you moved on. In the time from '93 to '97, you were General Manager of the Technology Development Center?

Masuhara: Yes.

Fairbairn: What was the most important program or programs during that time?

Masuhara: As I told you, I had to work in many areas. If I had some problems for the analog process, I had to do some job for them. And for the package we had to develop chip size package, for instance. Design automation was another area. We were just trying to use Cadence, Synopsys, outside tools. So people have to work on the matching of the inside tools to outside tools. And in the process we have to develop fine line processes 1.3 to 0.8, 0.5, 0.3 micron.

Fairbairn: So all of this at the same time.

Masuhara: All the same. But in terms of the economy, Hitachi semiconductor was not successful in a sense. 4M DRAM was successful as I told you. Maybe that was the last Hitachi DRAM that was successful. So we had a lot of problems for the DRAM.

Fairbairn: So Japan in general and Hitachi in particular was very successful, especially in the DRAM area and people like Intel and others left the business because of the low cost and high quality that Hitachi and other Japanese manufacturers were able to produce. Why was Japan and Hitachi in particular so successful at that point? And what were the decisions or developments, which changed their fortunes and made it more difficult going on? Can you describe what..?

Masuhara: That's very big question, tough question to answer. Well, I should say, during 80's, for example..

Fairbairn: I like your opinion. There are many people with many opinions or whatever. You were involved very directly with the development of these products. What is your opinion?

Masuhara: During 80s, I think the society of Japan did have some leading edge in many areas. For instance, consumer product was very successful, game product was successful. And semiconductor was, probably, power for them. So we had very good relationship between semiconductor industry and those application industries. Maybe in computer, United States has been governing the world. In personal computer also the United States was leading the world. So what's important is that you have to have the application and the semiconductor product insside the society so that you have to have the needs, or I should say, what kind of technology you need, what kind of modification they need very quickly. I think we could establish that kind of relationship in Japan, inside Japan. But at the same time, industry in Japan failed to create that kind of relationship after the digital invasion or digital culture, for instance. For instance, professor in the university analyze that kind of things. If you had digitalization, which makes the part to be very popular in the world, it could create the world market very quickly. So Taiwan, for instance, becomes to absorb the semiconductor product from Japan very quickly, and produce their parts for the world in terms of personal computer, for instance. And, also, game computer, game machine in Japan was very successful during probably 80’s and the beginning of the 90’s, but it failed again. For instance Sony, Nintendo, Sega. Hitachi particularly had good relationship between Sega and Hitachi. So we provided the MCU, MPU to Sega. Kihara-san for instance, works in that area. Sega later was not in good situation, because they failed in developing a good game-computer. Sony remained in the game-computer area. So I think the good relationship between the application and semiconductor part is very essential motive force for the semiconductor to become successful, I think.

Fairbairn: Now in the DRAM area, you already had a successful product as the 4 Mb level, but found it difficult. Was that mainly an economic problem, that is the cost of building new fabs and so forth and unwillingness to make the investment? Or were there technical issues that were problems as well?

Masuhara: Well, another thing I didn't point out was that in Japan, in this country, manufacturing had strength. People in this country were very keen on increasing the yield by decreasing the dust numbers, things like that. But if you once implement that technology into the machines, manufacturing equipment, then become very popular to anywhere in the world. So Japanese industry had the advantage when the manufacturing technology was superior in terms of decreasing the dust number to increase the yield. Once it is implemented in equipment, all the semiconductor manufacturers had the same tools, equipment. That's one thing. Another thing was that almost all the application industry moved from Japan to Korea. For instance, consumer market went to Korea and game computer is now implemented in the smart phone. So, Japanese industry was not following that kind of movement, I think. That's another failure.

Fairbairn: That's an important insight, so thank you. So you then made some changes after you were at the Technology Development Center. You then took on assignment at asset association of..

Masuhara: Yes, it was, as a matter of fact, called ASET, Association of Super-Advanced Electronics Technologies. It's a kind of consortium. Actually, it was a consortium with almost 30 companies or so. And I became one of the sub-leaders of the project called MIRAI, developing future technologies.

Fairbairn: What was the reason for the formation of ASET and what companies or groups were a part of that?

Masuhara: Almost all the semiconductor manufacturers, equipment manufacturers, also some application manufacturers. And when I supervised the MIRAI project, the beginning of that project was led by METI of Japan. We had some kind of discussion in 1999. What should we do to re-innovate the semiconductor industry in Japan. Actually, Dr. Makimoto was the head of that project. The name of that project was called SNCC. I was one of the members of that project. And since we have to work in a pre-competitive area, people decided to develop some pre-competitive, far looking area in processes, design, things like that. So they decided to initiate the company Selete, and STARC. Those are the private companies, jointly invested private companies. METI also decided to provide some money, to initiate a project, national project. And the New Energy and Industrial Technology Development Organization NEDO proposed a seven-year project and asked soliciting proposals. Actually, companies that wanted to apply the project had a joint discussion what we should propose to NEDO.[1] So NEDO acquired the project and provided some money.

Fairbairn: Okay.

Masuhara: So…

Fairbairn: And it was for mainly around doing pre-competitive research and development in next-generation--

Masuhara: That's right.

Fairbairn: --process technology or…

Masuhara: Process and device technologies.

Fairbairn: Device technology.

Masuhara: In the MIRAI project, we have chosen five areas. One is high-k gate dielectric, and low-k dielectric for interconnects. Then, new transistor structure. We mostly work on the strained silicon, or silicon-germanium transistors. Then, lithography measurements, measurement technology for lithography. And the last area was-- let's see. GA--

Fairbairn: Genetic algorithm?

Masuhara: Genetic algorithm.

Fairbairn: Uh-huh.

Masuhara: To use genetic algorithm to adjust the circuit characteristics. So we have chosen five areas. And we asked the public who want to be the member. Actually, we have chosen 24 companies, including Intel, and Samsung. So it was a kind of international project at the beginning.

[1] METI (Ministry of Economy, Trade, and Industry) get budget for NEDO. NEDO determines the project specification and ask soliciting project proposals to public. The companies that wanted to apply for the project submit a proposal to NEDO, not METI. [interviewee's note]

Fairbairn: But the work was being done here in Japan in--

Masuhara: In Tsukuba.

Fairbairn: Okay. This last area, genetic algorithm for low-voltage ICs we're addressing, what kind of-- tell me more about that. I don't understand that area.

Masuhara: Oh, in those things I think I'd better show you. You have the copy, let's see.

Fairbairn: I have this. Is that--

Masuhara: That's right. I have the copy of this overview article, actually, this article.

Fairbairn: Is it called "Overview of CMOS Technology Development in the MIRAI Project"

Masuhara: CMOS Technology.

Fairbairn: "--in the MIRAI Project." Okay.

Masuhara: I wrote this article several years ago for the IEEE Solid-State Circuits Magazine.

Fairbairn: Yes. I have a copy of that.

Masuhara: Yes. And I think I have chosen one figure about this for the genetic algorithm.

Fairbairn: Okay.

Masuhara: On Page 10 to 11, on this page.

Fairbairn: Yes.

Masuhara: People in the AIST, which is national lab, had the technology to use genetic algorithm. Actually, they developed a technology, for instance, to use for the artificial hand. If you lose your arm, you can create your artificial hand. And you can move the hand. But you have the current, muscle current or something. And if you educate how to control the muscle by using that current, you can handle your hands.

Fairbairn: Yes, yes.

Masuhara: And people in the AIST had been working to apply genetic algorithm to educate that kind of things.

Fairbairn: I see.

Masuhara: Okay. So they tried to use this to educate semiconductor circuits.

Fairbairn: I see.

Masuhara: So this is one of the applications. They applied the technology to clock trees.

Fairbairn: Okay.

Masuhara: As you know, clock trees were very critical area in the circuit.

Fairbairn: Yes.

Masuhara: So if you have that kind of genetic algorithm and if you have some adjustment to this circuit, you can increase the yield, like this one.

Fairbairn: I see.

Masuhara: This is another application. If you have long transmission line, and if you detect a signal at the end of the transmission line and if you modify the signal at the sending-portion, you can have a very good eye (like it was shown in the figure).

Fairbairn: I see. Yes.

Masuhara: So we have chosen this technology of the genetic algorithm.

Fairbairn: So that was in 2001

Masuhara: Yes.

Fairbairn: And how long did that continue, and was it, did you feel it was successful? Did the companies get the value from the project that they anticipated?

Masuhara: Yes, I should say. We were successful in terms of very fundamental theory and knowledge. For instance, in the high-k development, during that time, Intel people were very keen on developing and to apply high-k insulator for the FinFETs

Fairbairn: Yes.

Masuhara: And we didn't know how to control the threshold voltage by using that kind of materials. Professor Toriumi of Tokyo University was the head of the high-k group. He found that dipole, which exists in the high-k material, is a cause of the high-k threshold voltage. And we applied an atomic layer deposition technology to control the dipole. That control of the threshold voltage was very successful and was applied, and they got some patents on the technology to be applied to industry. In a sense, that was successful, but since we are not working in a very competitive area, actual product, depends very much on the actual industry part.

Fairbairn: Right. So how long did that consortium stay together?

Masuhara: I worked in that consortium for seven years.

Fairbairn: Mm-hm.

Masuhara: Actually, MIRAI Project stayed 10 years.

Fairbairn: Okay.

Masuhara: But we left after the seventh year.

Fairbairn: And was it subsequently dissolved, or is there some consortium activity still going on today in this area?

Masuhara: We finished the MIRAI activity, and transferred the technology to industries and universities. And for instance, there's an organization called EIDEC, which is working now on the extreme-ultraviolet technology, EUV. And for instance, one of the technologies in the lithography measurement group has been transferred to that company, that is, the inspection of the mask, mask blanks. In the mask, the detection of the dust on the mask is very important as you know. And in the EUV technology, it's very difficult to measure the mask blanks because extreme-ultraviolet has very short wavelength. You have to use the at-wavelength instruments, sensing instrument. We developed that technology, basic technology, and transferred it. People still are working in that area.

Fairbairn: Okay. So is there any new consortium, is there any consortium activity between the Japanese semiconductor companies today developing new technologies?

Masuhara: As I have written in that article, we initiated another project called "Low-voltage Technology for Low-carbon Society".

Fairbairn: Okay. For low?

Masuhara: Low carbon.

Fairbairn: For low carbon.

Masuhara: Carbon.

Fairbairn: Low-carbon society. Right.

Masuhara: Society.

Fairbairn: Okay.

Masuhara: And we established an organization called LEAP. And I--

Fairbairn: And so you also are involved in that?

Masuhara: Yes. I become the President of LEAP.

Fairbairn: Low-power Electronics Association & Project. And are these mainly semiconductor companies or other companies as well?

Masuhara: Ten companies joined the project. Actually, nine companies joined the project first time, and then one company later joined the project.

Fairbairn: Is this also involving METI or other government groups?

Masuhara: Actually METI decided to initiate the project, and solicited applications in public. So, any company could apply. And 10 companies decided to jointly propose a project, and that was the initiation.

Fairbairn: Okay. So you've been involved in that from 2010 to 2015?

Masuhara: 2010 to 2015.

Fairbairn: And just tell us what the major focus of that was and what kind of results you saw over that time.

Masuhara: Well, as a matter of fact, this society relies, very much on the information, electronics information technology. And those are basically made out of two portions. One is very huge data centers. For instance, Google, has very huge data centers. That's consuming a lot of power.

Fairbairn: Yes.

Masuhara: And, you know, power is increasing year by year. Another portion is very low power technology. Now, for instance, if you want to sense something by batteries, you have to have very low power integrated circuits. There are two major portions and all of these have very good connection in terms of low power requirement. And society relies very much on low power. And as I have written in this article,…

Fairbairn: It's okay. We'll get it. Yeah.

Masuhara: We have been hit by the earthquake, 2011 earthquake, and I was in Tokyo at that time. My colleagues were in Tsukuba in blackout.

Fairbairn: Mm.

Masuhara: So I found that during earthquake,

Fairbairn: This is the earthquake in 2011?

Masuhara: That's right. My lab in Tsukuba failed for almost six months or so.

Fairbairn: Oh, my.

Masuhara: Oh. Anyway, I had a talk at the A-SSCC. I was invited to have a plenary talk at Asian Solid-State Circuit Conference, which was held in Jeju. And I included some photographs of the earthquakes. And I had a picture. I'm not sure I have a picture in that, because I didn't use that. Maybe, I couldn't use the picture, because of the problem of publicity. Anyway, I still remember, there was a picture taken from the satellite of Japan in the night of the day of the earthquake, in which a lighted portion having electricity existed only in the area which is not hit by the earthquake. Only lighted portion hit by the earthquake was the Fukushima Daiichi area. Fukushima Daiichi is a nuclear plant, and we had a nuclear disaster. You know, people were busy working at that time in the area.

Fairbairn: Yes. Yeah.

Masuhara: So anyway, I found that if you have something like that, electricity would become very important. And you have to have an electric system, electric connection in between, your smartphones or sensors, to the base stations that is operated by batteries. But I still remember, I included one of the figures, which was taken from the professors of the University of Electro-Communications, Professor Ichikawa. He was working on the very low-power suitcase-size base stations. If you have that kind of things, you can carry that. You can operate the system.

Fairbairn: Right. Otherwise you have no communication between cell phones--

Masuhara: Oh, that's right.

Fairbairn: --or any of the other things, yeah.

Masuhara: That's right. I still remember, I was in Tokyo, and I have to move back to my house, but there were no trains operating. But fortunately, I have electricity in Tokyo office. I stayed in the office overnight, so…

Fairbairn: Oh.

Masuhara: But my wife was outside my house, so there was no, no--

Fairbairn: No power, huh?

Masuhara: No power. She had power for handset, but there was no way to communicate with her. So maybe during midnight I had communication, with me and my wife. That was very cold night in March. And she was going to the center of Tokyo. But all of a sudden, electricity failed and she was in the train. And, there was no way to go out, so… But fortunately, there was a car to carry her to one of the nearby schools or something where they had heating. So she stayed there overnight. And we met next morning.

Masuhara: Anyway, I was lucky in Tokyo.

Fairbairn: You didn't know where she was, I presume, right?

Masuhara: No. There was no communication means until midnight. I am not sure where she was at that time.

Masuhara: So I think electricity is very essential. Reducing electricity is also essential. So we decide to initiate a project. We had five groups in LEAP. First group was working in the new transistors. I should say beforehand, most of the integrated circuit, right now, is working around one volt, recently. And since I worked, from the beginning of my career, to reduce it from five volt to one volt, I am very keen on reducing the power, voltage.

Fairbairn: <laughs>

Masuhara: So we decided to decrease the voltage down to 0.5 volt. First group decided to work on the integrated circuit that could be operated down to maybe 0.35 volts or so. So they have chosen the new transistor, called SOTB. I'd like to explain a little bit more. And the second group decided to work on, I should say three groups decided to work on, non-volatile memories. One of the groups decided to work on the magnetic MRAM, so-called STT-MRAM (Spin-Torque-Transfer-MRAM). Second group decided to work on the phase-change memory for storage. The third group decided to work on the electric switch, so-called Atom-Switch. And we had three, very interesting non-volatile memories and switches. And the last group came from Toshiba, Tokyo Electron, and Ebara. They were very keen on developing interconnect technology for the flash memories. And since Toshiba is very keen on developing flash memory technology, they decided to work on the three-dimensional wiring, interconnect, using carbon-nanotube and graphene. Okay, so we had five very fundamental technology groups.

Fairbairn: Yeah. Very advanced technology.

Masuhara: And, you know, it was very tough for us for the second year (2011), because of the earthquake. We couldn't operate the clean room for some period due to power. So we had to do some analysis. That was all, for half a year.

Fairbairn: So without power, this is your lab, right?

Masuhara: Yes.

Fairbairn: Where did you work or, I mean… You had to work someplace else.

Masuhara: During that time, we had to do an analysis or design processes, things like that. Only lab that worked was--, we had a lab as well in Toshiba. So the Toshiba lab could be used for the purpose, but only for the carbon wiring. Other lab, especially in the AIST lab, we had a failure. We had to wait for, I should say, three months. They worked very hard to rebuild the lab for three months. They succeeded in operating the lab, fab, in June, I think. So we were successful. And also we were using, actually, what we had done was we developed the basic process in Naka works of Renesas Electronics. What we decided to do in that project was to do, to integrate, the back-end process, the wiring process, in the AIST lab. But the front-end process was done in Naka works of Renesas. Renesas fab also failed at that time. But since Toyota has been using their product, almost all the automobile company has been using their MCU, they helped a lot to rebuild the Renesas fab. I should say, they were forced to rebuild very quickly. So two labs succeeded to work again.

Fairbairn: But it still took several months to--

Masuhara: Several months.

Fairbairn: --get them working again, right?

Masuhara: Yes, that's right. So it was tough experience.

Fairbairn: Yeah.

Masuhara: So, you know, first and second year of that project was very tough.

Fairbairn: So, I mean, it's one thing for the fab not to work, but that meant that the homes and everything around there also did not have power, correct? Or…

Masuhara: Oh, well, I should say power came back very quickly.

Fairbairn: Oh, I see.

Masuhara: In that area. But the problem was the electricity shortage. Since Tokyo Electric Company, had a shortage of electricity for several months, first several weeks was very tough for us. For instance, in Tokyo we had so-called partly blackouts. Tokyo Electric Company decided that which area in Tokyo, go into blackouts for what time. Since I lived at the edge of Tokyo, I had to change my trains three times. Each train area belonged to different blackout times. So I had a lot of problems in commuting. But that was Tokyo area. We did have the electricity. But in Tsukuba area, since we had a shortage of electricity, the AIST organization had to reduce the usage of electricity. So we couldn't turn on the machines.

Fairbairn: I see.

Masuhara: It was very tough for us for six months.

Fairbairn: Right. Right. Hm. So can you describe, after all these problems, what kind of progress or what important developments did you accomplish as part of the LEAP program.

Masuhara: Okay. We succeeded in operating the integrated circuits at 0.3 volts or so. For instance, as everything is in this article here on pages 25 to 30 This is the integrated circuit. And this is the SRAM on Page 29 which is fabricated in the third year of the project.

Fairbairn: Okay.

Masuhara: Using the SOTB. By the way, SOTB has, two kinds of devices. It's a kind of very thin SOI, silicon-on-insulator transistors, CMOS transistors, and bulk transistors, bulk CMOS, on the same substrate. So by adding one or two masks, you can make the SOI device. What's good for the SOI device is that you can have a very thin (lightly)-doped substrate or active layer for the transistors. So, you can reduce the variation of the threshold voltage. I didn't include the variation of the threshold voltage for this article. I have written the result, in the Chapter Two of the book called "CHIPS 2020." Volume Two.

Fairbairn: What is the title of that article?

Masuhara: This is “The Future of Low-Power Electronics.”

Fairbairn: Okay.

Masuhara: And in this figure here, I have compared the variation of the transistors. This is, by the way, the cumulative probability, and this is the voltage. And this is the variation. So, this means that the black part, which is the usual standard transistor, has the variation from 0.4 to 0.8 volt. But if you fabricate the device by using the SOTB thin (lightly)-doped active layer device, the variation could be reduced to this value, 0.4 to 0.55 volt.

Fairbairn: I see.

Masuhara: Yes. Another thing you got, you can control the substrate voltage of this device by using the insulated back gate. So you can have very wide range of back gate biasing. At the last year of the project, we have fabricated the substrate voltage generator, which could be integrated on the chip. We have not combined those together, but we have made an ARM microprocessor and the voltage regulator on the same substrate.

Fairbairn: Hm. And with reduced voltage, what…

Masuhara: There are some results. This is the example. This is not the ARM processor. This is the processor which we got from Renesas Electronics, V850 microprocessor, having two SRAMs. And this is voltage, and this is energy. Here you can see around 0.35 to 0.4 volts, this is the minimum voltage. Okay.

Fairbairn: Minimum. Right. So do you have an ARM processor working at .35 volts?

Masuhara: Yes.

Fairbairn: I see.

Masuhara: So this is one achievement. And another thing that we have developed, was so-called Atom-Switch, which is--. Maybe I should use a bigger figure.

Fairbairn: Can you leave us these articles, copies?

Masuhara: Yes.

Fairbairn: Okay. So this is in the-- what is the name of this article or presentation?

Masuhara: I have chosen some of the figures from the SEMICON, Japan, Technology Symposium, and the lecture at University of Tokyo. So this not totally public.

Fairbairn: Okay.

Masuhara: But most of the things have become the public domain. This is the switch. And this is the polymer solid-electrolyte (PSE) in between the two electrodes. If you apply the positive voltage to these terminals, then you can create a conductive bridge.

Fairbairn: I see.

Masuhara: And you can use this bridge from here to here for a kind of switch. You probably are familiar with the FPGA.

Fairbairn: Mm-hm.

Masuhara: Which have a SRAM switch and a transistor, to generate the logics. And you can combine all of these functions.

Fairbairn: I see. Uh-huh.

Masuhara: And as you can easily imagine from this figure, in ASIC technology you have to design the mask and manufacture mask first. And then manufacture the whole integrated circuit. So it consumes a lot of design time and money.

Fairbairn: Yes.

Masuhara: Okay. FPGA chip area is relatively large as compared to ASICs

Fairbairn: Basic. Yes.

Masuhara: And the power could be, moderate. But this is zero. No design cost. Time to market is zero for the CAS-Switch, much better than FPGA in term of the chip area and power, and almost the same characteristic as the FPGA.

Fairbairn: I see.

Masuhara: So actually, this is one of the examples to design the logics by using this. This is a very simple look-ahead table or crossbar switch, using Atom-Switches. And what's good from here is that you can integrate the switches on top of the logics. And by using this programmable logic array, we have also made the circuit. That means that you can make an MCU with your own logic on the same chip, your own programmable logic.

Fairbairn: So you developed this switch as part of this LEAP program?

Masuhara: Yes.

Fairbairn: Mm-hm.

Masuhara: That's why I told you three types of non-volatile memories were very essential. This is one type of the memory switch, okay?

Fairbairn: Okay.

Masuhara: Another is also interesting too, but I don't have time to describe all of them.

Fairbairn: That's okay. We don't have to go into the technical details.

Masuhara: Okay.

Fairbairn: So you were working with LEAP until 2015, about a year ago?

Masuhara: Yes.

Fairbairn: And did you retire after that or what is your current activity?

Masuhara: I just have retired. After writing that book, I'm still serving some Japanese prize committee.

Fairbairn: Have some time for golf or other activities? Tennis? Are you…

Masuhara: Well, I hoped to play golf but I didn't play, so actually, I don't play golf anymore.

Masuhara: I'm still keen on playing tennis. But I'm still a little bit busy too, but…

Fairbairn: Too busy

Masuhara: A lot of my friends invite me to play tennis, but I should train my body first.

Fairbairn: Have to get back in shape, huh?

Masuhara: That's right.

Fairbairn: Well, it's been very interesting sharing your story. Is there anything that you think we've missed or that you would like to conclude with before we…

Masuhara: Well, I'm very interested in, what kind of things should happen in the future. As I told you, what's important is the low-voltage device for the future. And I also found that, for instance, during my train from my house to here, I found a lot of people playing on the smart-phones.

Fairbairn: Yes.

Masuhara: Is that good for his brain?

Masuhara: Or not?

Fairbairn: We don't know.

Masuhara: And what kind of things need to be done for the IT for the future. It is said that in the internet, IoT is going to the way to go. But people couldn't find, the way to go to which area, which industry area, for the economical reason or also for the human.

Fairbairn: Yes.

Masuhara: Which area is important?

Fairbairn: Right.

Masuhara: I'm not sure is artificial intelligence good way to go? We should consider lot more. You also have to have another kind of danger. For instance, IT society has a lot of danger. One of my colleagues sent me an e-mail stating that his e-mail address had become public through some company in Japan. That kind of things may happen very frequently in the future. So we need to create a safe and a smart society. That could be the message I can leave.

Fairbairn: Oh, good. Thank you very much. I think that's a very worthwhile comment and warning. There are many things this new technology is capable of. Not all of them are good things, but…

Fairbairn: So directing them in a positive direction is going to be very important. So thank you very much for sharing your time and thoughts with us.

Masuhara: Thank you very much.

Fairbairn: And we very much appreciate it.

Masuhara: Thank you very much.

END OF INTERVIEW

