Oral History of Simon Sze

Interviewed by:
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Jeff Katz: Good morning, we are at the Computer History Museum on February 11th 2014. I'm with Dr. Simon Sze. And I'm the interviewer. We're going to do an oral history of Dr. Sze and his experiences with early and very important semiconductors, namely the invention of the floating gate, which is a fundamental piece of all non-volatile memories. We'll get into that in a little while in more detail. Dr. Sze, I'd like to start with some easy questions. Tell us a little bit about your early life.

Simon Sze: Okay.

Katz: Where were you born? Where did you grow up? And what was your family background?

Sze: All right. I was born in Nanking, China, on March 21st 1936. That's more or less during the Chinese Japanese war. And my father was a mining engineer. Actually, I originally decided to study mining, but I changed my mind later. And around twelve [in 1948], when I was twelve years old, we moved from mainland China to Taiwan. So, I did my middle school study there, and then my college there. After I graduated from the National Taiwan University, I came to the United States.

Katz: Did you have siblings that came along?

Sze: Yeah, one brother two years younger.

Katz: And were you all a technical family if your dad was a mining engineer?

Sze: My brother is a chemical engineer.

Katz: Ah-ha.

Sze: I'm an electrical engineer.

Katz: What prompted you to move in that direction, toward electronics or electrical--?

Sze: Originally, I tried to study mining and metallurgy like my father. But you know Taiwan has very limited minerals underneath. So, I finally decided to study something else in engineering, since I thought I was pretty good in math, and someone told me that electrical engineering needs more math. That's the reason I decided to get into the electrical engineering.

Katz: Uh-huh. That's sort of the same way I got into it. I found out in early school I was good at that stuff.

Sze: I thought engineering's interesting, yeah.

Katz: Well-- so, why did you choose the universities that you did, both in Taiwan and later in the U.S.?

Sze: Undergraduate is easy because [The National] Taiwan University is the best university in Taiwan. So, I entered it. And after graduation, I applied for admission and a scholarship. I did not get a scholarship to couple universities in the United States. And one of my friends and classmates already attended the University of Washington in Seattle. So, I applied to UW and got an admission. Yes, I went to the University of Washington. After I got my master's degree, I applied to Harvard and Stanford for the PhD program. [Sze: I received a scholarship from both universities.] And finally I decided to go to Stanford because Harvard has no electrical engineering. They have only applied physics. And Stanford has electrical engineering. Another reason is that someone told me, if I wanted to get a PhD in UW, it might take four to five years. At Stanford, it's only two years.

Katz: Ah--

Sze: Which is almost true. Actually, I got my degree in Stanford in two and a half.

Katz: Very interesting. Did you have any particular mentors through your university days, that influenced you in the direction that you ended up?

Sze: Oh, very important. At University of Washington I met professor Ling Y. Wei, W-E-I, who's a semiconductor physicist. That's the reason I got into semiconductors for a Master's thesis with a diffusion of zinc and tin, in indium antimonite. And while at Stanford, I met a famous mentor, my advisor was professor John Moll, M-O-L-L. Moll's very important-- most people don't know. He is the one who proposed silicon as the most important material for semiconductor devices.

Katz: Ah. The move away from germanium.

Sze: That's right. Because in the early '50s the whole Bell Labs was working with germanium. When he joined Bell Labs in 1952, he proposed silicon. He thought silicon is much better than germanium. Now, we have Silicon Valley here.

Katz: Yes, we know about it now. But let's get a little bit technical. Can you describe a little of that reasoning why silicon became more attractive to him?

Sze: I think there were three reasons. First, silicon has the right band gap, 1.12 eV compared with germanium, which only 0.66 eV. The larger band gap gives you lower leakage current. So, that's very important. Secondly, silicon has a very good oxide. Silicon dioxide is the perfect insulator on top of silicon.

Katz: That's the one I had heard of.

Sze: Yeah, that's the second reason. The third reason, maybe even more important, is the low-cost of silicon. Because silicon constitutes twenty eight percent of the Earth's crust.

Katz: Yes it's very abundant.

Sze: Second to oxygen. That's a reason. All the three reasons make silicon very attractive. That's the reason we have Silicon Valley here.

Katz: I understood the second two, but that's the first time I'd heard about the band gap issue too, as well.

Sze: Band gap's important. Germanium's band gap was too small, so the leakage current was too high. Now, that's the reason why it's not very useful.

Katz: Very good. So, you became an early silicon advocate I presume.

Sze: Oh yeah, I worked with silicon all of my life. Yeah.

Katz: That's good. Let's move a little bit into near the end of your time at university when you were finishing up. What was your your doctoral thesis in?

Sze: My thesis was on the hot electron range in gold film. But it was made with a Schottky diode. It was [a thing] gold metal [film] evaporated on to a semiconductor. I was interested in the electron movement in the metal.

Katz: Having gotten all of that knowledge in you, you must have been attractive to a number of potential employers. How did you end up at Bell Labs?

Sze: Around the early 1960's, it was the golden age of semiconductors. I got seven offers from Bell Labs, IBM, HP, General Electric, Westinghouse, and so on. The reason why I went to Bell labs, which actually offered the lowest annual pay, twelve thousand dollars a year compared with fourteen thousand four hundred from GE, was because my advisor, Professor Moll, said that Bell Labs had a much better research environment. And he thought I was a good research guy. So, he recommend that I go to Bell Labs. So, I picked the lowest pay and went to Bell Labs.

Katz: [Jokingly] You can blame your advisor for your economic failure in life, is that it?

Sze: Actually, when I told him the pay so low, he said, “Don’t worry.” He said, “What’s important is dM/dT. M is the money. dT is the rate of increase of the salary.

Katz: That’s right, dM/dT.

Sze: And they did a pretty good job. They had pretty decent raises over the years.

Katz: That’s good. What were your first job things that you did at Bell Labs?

Sze: Ah, that’s important. I talked to my boss, asking what should I do? He said, “Very simple, anything to do with silicon, anything.” So, that’s really a very big subject.

Katz: <Laughs> That’s a good research environment!

Sze: I picked up a hot electron transistor first, since I had been dealing with hot electrons in my [PhD] thesis. And then I moved to a different thing, I studied the Schottky barrier. I wrote lots of papers on the metal semiconductor contact and also on avalanche breakdown. In the year 1967, I was having lunch with Dawon Kahng, my colleague. And we were talking about the replacement of core memory, because magnetic core was used in all computers at that time, and it was very slow. But it was very reliable. It’s a non-volatile memory, by the way. During one lunch we came up with the idea of the floating gate. So, that’s--

Katz: How did that idea come about? What was your Ah-ha! moment that made you think it was doable?

Sze: What happened was we were thinking about finding a semiconductor device to replace magnetic core memory. Okay.

Katz: Was that an assignment from Bell Labs?

Sze: No, it was just a lunch discussion. We could work on anything we wanted. We had no assignments, by the way. Our only assignment was working on silicon. And then one day we looked at the-- oh yeah, after lunch Dawon said that he was still hungry. He wanted to get a piece of cake, okay. So, he ordered I think it was a cheesecake or chocolate cake. It had four layers. And we were looking at it, see, and found it interesting. If we were able to replace the gate stack with one additional layer of metal, then just revise our MOSFET gate-- we came up with the floating gate idea, from the cheesecake.

Katz: That's a great story. I'll have to remember that when I give my little talks about semiconductors.

Sze: And then I went back to try to make this one. I had a friend Marty Lepselter who was an expert on metallurgy. He suggested zirconium, Zr, because zirconium is very easily oxidized. So, we could form the silicon layer with oxide. And then we could deposit zirconium. And we could oxidize it to form upper layer with zirconium oxide. Then we could deposit aluminum on top of that. That's the floating gate structure.

Katz: The idea of the electrons jumping across an oxide layer to land into the floating gate was not obvious.

Sze: That was well-known. That's called the Fowler-NordheimTunneling Theory.

Katz: Right, that had been around.

Sze: Quite a time, that's right. So, we knew we could tunnel electrons through oxide into a metal layer. Yes we knew that. However, to put a floating gate into the MOSFET gate structure was a novel idea.

Katz: Very interesting.

Katz: Was that one of your first projects then?

Sze: Oh no, that was already my twentieth project. I joined Bell Labs in 1963, and this was in 1967. And it was just one of the projects. I was interested in seeing after we had finished this one, we'd do some interesting experimental results, and saw they agreed with our preliminary theoretical analysis. We wrote the paper and I showed it to my boss. My boss looked it over and said, "This is absolutely useless." I said "How come?" He said, "Can you imagine any reason this would be useful?" And I said, "Well, we're trying to replace magnetic core memory." He did not agree. So he asked us not to publish this paper in IEEE Transactions on Electron Devices. Just publish in a less-known journal called the Bell System Technical Journal. That's where we published it.

Katz: Did it ever get circulated outside of Bell Labs?

Sze: Well, that publication was in the public. For example, Stanford has copies.

Katz: I see.

Sze: And then many other companies have copies. But no one paid attention to it, no one.

Katz: Well, somebody did.

Sze: Even in 1971, when Frohman-Bentchkowsky of Intel wrote his EPROM paper-- I remember he submitted the paper to JAP [Journal of Applied Physics]. And the reviewer told him his claim was incorrect, because someone already did the idea before. So, he was forced to put my Bell System reference into that paper. He acknowledged that paper was first. Actually, it was five years ahead of his.

Katz: Was there ever any manufacturing of the floating gates at Bell Labs or anywhere in the AT&T--

Sze: No. No. It was just put on the shelf, that's it. Yeah.

Katz: How many samples did you make, if any?

Sze: At that time, we had one small wafer with silicon. I think we made probably a couple dozen. I remember my technician Andy Loya, the same guy who did this one [holding up Lucite-embedded chip] with the MOSFET. I think he measured ten or twenty units. They were all pretty consistent, that is with charge storage. About the longest one was one hour, before its electrons were leaking out. Of course now it's a minimum of ten years storage. And sometimes it's as high as one hundred years.

Katz: We have ways to try to accelerate the theoretical life of those things, but we don't really know until we wait a hundred years do we?

Sze: No.— When we made the first one, I think the oxides were very leaky. Yeah, and that's the reason. Now, we make a much better oxide. If you use a camera with a flash card, you have a guaranteed ten years storage.

Katz: Indeed.

Sze: I have some flash cards that are over twenty [fifteen] years now. The pictures still look pretty good.

Katz: And that's right up there with-- well I guess magnetism is permanent forever. But in our world, ten to twenty years is almost forever.

Sze: Ten years is pretty long yeah, that's a good data retention time.

Katz: Were you involved at all in that first MOSFET activity?

Sze: No, I was not. You see I joined the Bell Labs in 1963. The first MOSFET at Bell Labs was created in 1959. Before my time. Well, I was studying for my Master's degree then.

Katz: So, were they using MOSFETs all over the place by 1967?

Sze: No. Absolutely not. You see when Dawon wrote his paper with Atella at that time, that paper was not allowed to publish. The reason —was it was not a junction bipolar transistor.

Katz: Mm-hmm.

Sze: It's useless, so fortunately--

Katz: Same reasoning.

Sze: Yeah. Fortunately Dawon submitted a paper to a conference called the Device Research Conference. So, at least it was presented at DRC.

Katz: Was that The Solid State--

Sze: Yeah, I guess it was called the Device Research Conference [DRC].

It was a small group. And the paper was published as an abstract. Yeah. So, at least he did--

Katz: The credit is known where it needs to be. But it's interesting that the Bell system had all these wonderful ideas but did not exploit them early.

Sze: That's right. It's quite interesting, I don't know why.

Katz: Can you describe some of the other things you worked on at Bell Labs, leading up to the ah-ha moment for floating gate, and then beyond it?

Sze: The floating gates weren't the only project. We were working on many different projects. And I collaborated with at least twenty different people within the Bell system. You see at that time, Bell Labs has about thirty thousand people with a budget of about three billion dollars. Now, that was--

Katz: Were they all in Murray Hill?

Sze: No, Murray Hill had only about five thousand. And we had another five thousand in Holmdel, and maybe one thousand in Allentown or Reading. There were twenty different places. It was all over. It was the research arm of AT&T, American Telephone and Telegraph Company.

Katz: Correct.

Sze: And they tried to recruit the best people, and to give them the freedom to do whatever research related to computing and communications they wanted to do.

Katz: Was your work all in Murray Hill or did you move around?

Sze: No, I was in Murray Hill all my [Bell Labs] life, twenty-seven years.

Katz: Did you have to do much travel?

Sze: Yeah we did. Sometimes we'd go to Allentown. And sometimes go to Reading for some special discussions with the people there because though we invented or developed it, they were trying to manufacture it. So, if there were some technical problems we'd have to communicate how to improve the device performance, for example.

Katz: Are there any other particular projects that you worked on of which you are very proud?

Sze: Well, another project is my book writing. That's very unique. You know not too many people at Bell Labs write books. Around the 1967, I was drafted by my boss to teach an in-house course. That is, we had to take some courses either as a student or as a teacher. So, I decided to be a teacher. I went into the library there to try and find a textbook to cover semiconductor devices. But most-- actually, all the books [were] mainly concerned with one device, [the] transistor. But I wanted to cover much more. So, I prepared class notes. And those notes eventually became a book, after I spent three thousand hours on it to write it.

Katz: Wow.

Sze: That's my first book. I brought a copy for you.

Katz: I and the museum will appreciate that.

Sze: It was published by Wiley in 1969. And after that, I've been involved with many, many book projects.

Katz: Was it published by Bell Labs, or some vanity publishing house or what?

Sze: I was very lucky because before 1967, I was told all the royalties from the book belonged to Bell Labs.

Katz: Mm-hmm.

Sze: For example, Shockley had written a book called the "Electron and Holes in Semiconductors". I don't think he received any royalties. It all went to Bell Labs. But after 1968, they wanted to encourage people to do more writing. So, the royalty went to the author. And I got my royalty from all of my books with Bell Labs.

Katz: Did that book become used in academic areas?

Sze: Yeah, it has become pretty popular, that's right. It was on the best-selling list for many, many years. **A**fter-- let's see, nineteen-- yeah after about ten years or so, Wiley urged me to write a second edition. So, I did it in 1981.

Katz: Yes, there had been a lot of advances in those ten years.

Sze: Lots of changes, that's right. Especially we got the room temperature laser. And then the MOSFET became very popular, and so on.

Katz: Okay, any other silicon based research that you did that we know about today?

Sze: Let's see-- for example, I did extensive research on the metal semiconductor contact we call Schottkey barrier. I think we did original transport theory on that, which still stands as the fundamental theory on the Schottkey barrier. And also I did many, many papers on avalanche breakdown, a multiplication within the junction, that is breakdown voltage.

Katz: When you had come up with an idea and demonstrate its feasibility, and then write a paper about it. Where were the papers published or delivered?

Sze: Usually, we published in IEEE Transactions on Electron Devices or in The Journal of Applied Physics. And after 1980, IEEE had a new journal called the Electron Device Letters. My boss [at Bell Labs] George Smith,was the founding editor of EDL. "**T**he Electron Device Letters" was issued on January 1st 1980. Actually, I served as an associate editor of the journal for about four or five years. When George Smith retired, I became the editor of the journal for about five years.

Katz: I see.

Sze: And then when I retired someone else took it over.

Katz: So, you were with Bell Labs a total of twenty-seven--

Sze: Twenty-seven years, from 1963 to 1989.

Katz: During that period of time, did you do any outside teaching as well? I know you ended up being a teacher.

Sze: Yeah, I took a few leaves of absence from Bell Labs and spent some time in Taiwan teaching at the universities there.

Katz: When did that happen? And how many times did it happen?

Sze: Let me see now, the most important one was 1968 to 1969. That is when I finished my first book. I submitted my manuscript, and I went to Chiao Tung University to teach for one year.

Katz: I bet you were perceived as a very valuable resource by the university, by the academic community having come out of that big research environment.

Sze: Yes. I tried to establish a basic semiconductor lab at the university. And also I served as the chief advisor to the first ever engineering PhD program in Taiwan, for that matter also in China. The first engineering PhD graduated in 1970. No one before that had the engineering PhD.

Katz: As I recall, when I was in the computer industry in those days, we kind of felt that the academic community was a little behind us because a lot of the basic research was being done by companies like Bell Labs and IBM, and others. We were teaching the universities how to teach the students. So, whenever one of us went on sabbatical or on a leave of absence, we were encouraged to go to universities and sprinkle our knowledge among the next generation.

Sze: Even at Stanford, for example, when I graduated in 1963. I think they had very, very poor equipment compared with Bell Labs.

Katz: Well, that was a remarkable accomplishment to stay at Bell Labs in research the whole time. Were you always basically a researcher, or did you become a manager of researchers?

Sze: Let's see now. I think I would have liked to do that, but I was promoted to group supervisor around 1969, after I returned from my one-year sabbatical. I was in charge of a small group, up to about ten people. Basically, I left them alone.

Katz: That's what you're supposed to do with researchers, right?

Sze: I just tried to help them if I could. And I tried to ask my boss to get money for them to buy equipment and to attend all different conferences and so on.

Katz: From that research environment, with the knowledge that some of the products, some of the ideas would turn into products that Western Electric or others would use, what was roughly the percentage of good ideas that ended up in modern computing, all of them, or half of them, or ten percent, or what?

Sze: Okay, let me see now. That's interesting because right now if you count all the semiconductor devices proposed by the world semiconductor community, about a hundred and forty at least. Among the hundred and forty, I think the useful ones [came to] maybe eighteen. Out of that eighteen, I think over ten were invented at Bell Labs.

Katz: Those ten devices were out of how many that were totally worked on in that research environment.

Sze: Lots of them.

Katz: Hundreds I would presume.

Sze: Probably. I invented lots of useless devices, published a lot of papers. Like hot electrons, we had ten different versions, all useless.

Katz: Why--

Sze: First, can I replace bipolar? And now, can I replace MOSFET?

Katz: Well, can you describe-- this is a little bit tricky question-- can you describe some of the things you thought might be really good ideas, but never really happened anywhere?

Sze: Okay. The first project that involved a hot electron transistor is a metal-semiconductor-metal kind of thing. Theoretically, it could be very, very fast. The hot electrons jump from the emitter fairly quickly to the base and collector. We thought at least a hundred times faster than bipolar. But it never worked because the output was too low-- the gain was too low. You see for a typical transistor the output alpha is 0.999, something like that. Okay. That would give you a very large beta. But for the hot electrons, the output's alpha was only 0.3. [$\beta=\alpha/(1-\alpha)$]

Katz: Ah.

Sze: It was useless, yes. No gain. But we spent almost two years on that, and wrote many, many papers on that. All useless.

Katz: Well here at the Computer History Museum, we like to collect not only the world famous successes, but we'd like to keep track of a few of the not so good ideas as well.

Sze: Yeah, some ideas you thought were great, but eventually you find out it's useless. There are lots of such devices really. In the hot electron family alone, at least ten, twenty different versions of hot electron devices [were] being proposed, all useless, I think, all useless.

Katz: Beyond the floating gate, which end products did you work on at the research phase of which you're the most proud?

Sze: Well, we're working on very small devices. You see the first MOSFET had almost twenty micron channel length. We tried to reduce it from twenty, to five, to three, to one micron, eventually to sub-micron. I did the first paper on 0.15 micron. That's a world record, using the E-beam process. Yeah, so that was the smallest MOSFET ever made in 1980. [In 1980, the channel length for typical commercial MOSFETs was 2 microns.]

Katz: That's interesting.

Sze: Yesterday I went to the ISSCC. They just announced a sixteen nanometer MOSFET. That is a 125 times reduction in size from the 2 micron MOSFET.

Katz: Yeah, we keep getting closer and closer to molecular and atomic limits.

Sze: But the fact that we can scale it down from twenty micron down to point one micron is a big job. It's very hard to do at that time.

Katz: Interesting. You brought with you, I noticed earlier today, an early version of the first MOSFETs. Can you hold that up again? I don't know if we can zoom in on that a little bit.

Sze: This is the first silicon MOSFET ever made.

Katz: It looks like it's about a millimeter square, one whole transistor.

Sze: One millimeter-- yeah that's right, one millimeter square. And the dimension of the channel length is twenty microns.

Katz: It's nice that we've been able to evolve as much as we have now to tens of nanometers. That's roughly a factor of 1000 improvement.

Sze: Tremendous improvement over the years, tremendous.

Katz: Did you have a sense while you were working on this stuff that it would be used in telecommunications, or in computing, or in what?

Sze: No, no sense at all. We were just doing research, just trying to push the frontier of whatever can be done. We really don't know what the end product will be used for.

Katz: Later after these things got done and somebody did put them into production somewhere, did you have a sense that you were contributing more or less to one end technology or another? Was it telecom? Was it computing?

Sze: One thing I noticed when I was in charge of a group, one project I was involved with is the IMPATT, I-M-P-A-T-T, that's [an acronym for] impact ionization transit time device. It's a microwave device, very powerful microwave device. So far, it's still the most powerful two terminal solid-state microwave device. It was used also in telecommunications.

Katz: Is that what's up on the towers as relay stations?

Sze: Sometimes they use it for that. I don't know if they still do or not. But I was involved with that, and we made lots of studies, and made some samples. Eventually, the technology was transferred into the production line in Allentown. We went there to talk to them and try to improve it. So, we know this idea was implemented in the production line.

Katz: Well, as part of the AT&T system, Bell Labs main charter was to come up with ideas that could be used to improve the performance and reliability of the telecommunications system.

Sze: Yes.

Katz: But a lot of it leaked into other industries. Like computing, and like automotive, and whatever else can take advantage of--

Sze: Because the transistor was used everywhere. Actually, Bell Labs gave away the technology really free, virtually no charge.

Katz: Was there a program to try to export that technology outside of the company and then get other industries aware of it?

Sze: I really don't know. Well, usually we published papers very quickly.

Katz: You published the ideas. Yeah. But you didn't have to go out and train people how to do things with it, did you?

Sze: No. No I never-- We just published it, and in all the major conferences such as IEDM, ISSCC and DRC [Device Research Conference].

Katz: Okay, well I'd like to know if you-- especially on the floating gate idea, if you had any contact with end users whether they were inside Bell Labs or outside.

Sze: No.

Katz: Did you ever discuss what they-- what the impact of your products could be?

Sze: To be honest, I didn't know even that it was ever used until around 1990, really.

Katz: Well, you must have been reading the papers in which people had cited your idea.

Sze: I knew the EPROM that is from [Frohman-Bentchkowsky at] Intel. And I knew the flash memory from Masuoka [at Toshiba]. Yeah, I knew that. But at that time, it was not very useful. You know it was not [widely] used until 1983 or '84 when Nintendo put EPROM into their game console so that they didn't have to always start the game from scratch.

Katz: Well, that was one of the highest volume uses of it, but there were other needs. Before microprocessors became high volume consumer products, they all depended on it [beginning in the mid 70s].

Sze: Yes, in a microprocessor when they turn on the machine. The boot up process was very, very slow. Again, the put EPROM into it. It now takes only a couple minutes, or less than a minute.

Katz: Out in CHM's Revolution exhibit, the first microprocessors we have all had EPROMs next to them.

Sze: Yeah, they call it BIOS [Basic Input and Output System].

Katz: Well, that was in later ones in the PCs in the early 80s. But even before the PCs, for embedded control, they needed something to hold the program. And it was usually an EPROM.

Sze: I think in the late '80s we knew it was useful. But we didn't know how important it is until around early 1990's. Suddenly, the cell phone shot up. Within a few years, it increased by three hundred times. That's incredible, and it's because of this non-volatile memory. Yeah.

Katz: Right, nobody that's trying to hold something in their pocket wants to carry around a hard drive.

Sze: That's right. NVSMs [Non-volatile Semiconductor Memories] made it so popular, it's amazing. Yeah, I was very amazed. Also, I feel sorry for Dawon Kahng. You see, he passed way in 1992.

Katz: And he missed a lot of the growth.

Sze: Yeah without realizing how important this device is.

Katz: It's very interesting that you didn't have contact with the end customer. That's unlike my own experience and many of the other people that we talk to.

Sze: That's typical for Bell Labs, by the way.

Katz: The genuine Ivory Tower, I guess.

Sze: Yeah, well especially in Murray Hill, we were supposed to do basic research. We didn't know what [would be] the use by the other people in the division within Bell Labs.

Katz: Did you have an idea at the time you were working on the non-volatile memories, on the floating gates, that it was scalable and therefore it could achieve pretty high densities?

Sze: No, no idea. By the way, they had to scale the MOSFET. Originally, when I joined Bell Labs first, bipolar was the king. Everybody was working with bipolar. But after, I think after '70s, that is after Intel announced the microprocessor in 1971, Bell Labs moved into the MOSFET very actively. My group concentrated in the research of MOSFET.

Katz: When you worked on any of these projects, well in particular the floating gate, what was the goal you were achieving-- you were seeking mostly? Was it just non-volatility? Or was it data retention time? Or was it speed to read and write, or what?

Sze: No, basically, we just tried to replace magnetic core memory. We failed because two months later, after our invention, there came another one called the DRAM by Bob Dennard at IBM. That one replaced core memory really in about seven, eight years, all gone. And however, DRAM consumed lots of power. I think DRAM consumes one hundred times more power than non-volatile memory. But who cares? You plug it into the outlet. You don't care. The old computers didn't use battery. So, they weren't concerned too much about the power consumption of DRAM. So, DRAM replaced all core memory.

Katz: Well, as an old computer designer, I did use DRAM to replace my cores. But I also preferred non-volatile for things that I didn't want to fool around in small space because DRAM needed much more support electronics.

Sze: It takes many, many years for memory-- I think the cross over point is only a few years ago that the industry produced more non-volatile memory to overtake the DRAM.

Katz: That's probably true, but that's because other applications than computers came around, mostly small space things that you keep in your hand or your pocket or on your body.

Sze: But now it's different. I checked: last year the production of the non-volatile memory, in just one year was more than the [production of all] DRAM over its entire history.

Katz: We can thank the phone and camera industry for that.

Sze: Yeah, that's right. The laptop industry is also--

Katz: Laptops and tablets and--

Sze: All the iPhone uses gigabit non-volatile.

Katz: Did you have any particular technical issues that were hard to overcome in developing the floating gate?

Sze: No.

Katz: So, the cheesecake analogy worked first time out?

Sze: Yeah, I got some help from my friend, Marty Lepselter. He suggested zirconium, which was a very good suggestion because by using zirconium, we could make the device, first time, successfully because we used a pulse to measure to the performance. And we got exactly what we wanted.

Katz: Before that suggestion came to you, what was in your mind to do instead of that?

Sze: We tried to use tungsten as a floating gate, but tungsten's very hard to deposit. It's such a high temperature metal. Zirconium's very easy. It just evaporates. And then put it into the tank with oxygen, it forms oxide. Then we deposit aluminum in the vacuum system. That's it.

Katz: So, the first time, it worked?

Sze: The first time, it worked, really. Yeah.

Katz: Wow. Right up there with Charles Babbage.

Sze: And then what we did is we did it again. That is we did it a second time, and measured the whole thing. It was almost the same. So, we were convinced that it was a real phenomenon. It's not something just happened.

Katz: Were you aware that anyone else, either inside the Bell Labs system, or outside at other companies, or academic institutions, were working on similar things? And did they have any influence on what you were doing?

Sze: There was one, but it was six months later. It was MNOS, presented at the IEDM in 1967. So, our publication, May 16th 1967 was the first description of the Floating-Gate concept. MNOS, which is a floating trap kind of thing was presented at IEDM, December 1967.

Katz: There was also the Ovshinsky kind of things that were going on around them.

Sze: Ovshinsky, I checked. Oh, no.It was one year behind,in 1968. So, Ovshinsky was behind us one year.

Katz: Do you think he was influenced by what you're doing?

Sze: Maybe. I don't know. We're one year ahead of him.

Katz: But he was into amorphous silicon, and it was a different kind of technology. The reason for my question was, I wonder how much influence you were receiving from outside, if any?

Sze: No nothing, nothing. Actually at Bell Labs, at that time when we published a paper it was almost without reference, because we were always the first..

Katz: <laughs>

Sze: …and there was nothing to refer to.

Katz: Well if you're out in front... there was a famous saying to look over your shoulder, make sure nobody's gaining on you.

Sze: Yeah.

Katz: But it's still nice to be in front.

Sze: That's right. For example on the breakdown voltage I calculated, [it was] also the first. At that time... many people believed that for gallium arsenide, the breakdown voltage was 10 times higher than for silicon, 10 times higher... at a given doping. And we had some gallium arsenide, it looked like that too, but I worked with a friend...

Logan in research. We measured the ionization rates and I computed the breakdown voltage, and I found out that gallium arsenide should be only about 20 percent higher than silicon. And then we made some very clean gallium arsenide and re-measured, and it did agree with our theory. So the 10 times sample turned out to be a very dirty gallium arsenide sample, they didn't know exactly what kind of doping was inside. So that's very interesting, yes.

Katz: Okay, you worked there for a long time and then retired eventually from Bell Labs.

Sze: That's right, yeah.

Katz: Did you stick with that kind of research work in your retirement?

Sze: No, no actually I joined National Chiao Tung University in Taiwan to teach, and also doing some research with the graduate students. But I liked to teach, yeah.

Katz: Let's stick to the research part for a minute and then we'll come to the teaching part.

Sze: Okay.

Katz: Did you contribute to any other interesting products or technologies that found their way into modern computing during that academic period of your career?

Sze: Let's see... well I think over that time, I think I taught at least 10 thousand students.

Katz: Ha.

Sze: And some were very successful, they've become either managers or professors at different universities.

Katz: So let's see, you started doing that in 1989 roughly?

Sze: Well, the earliest teaching was 1968. That's the first time, I took a leave from Bell Labs.

Katz: Taiwan was one of the first places outside of the US where personal computing and other computing was pretty well done.

Sze: That's right.

Katz: Were any of your students involved in that?

Sze: Oh yes, I think lots of them.

Katz: Any we should know about?

Sze: Well, for example Nicky Lu, after he took my course at National Taiwan University and then he also graduated from Stanford, and he went to IBM. And he developed the fastest DRAM ever, still the fastest DRAM, yeah. And he has a small company in Taiwan doing that. And also another one is Yen Sun, He became the vice president of TSMC, Taiwan Semiconductor Manufacturing Company.

Katz: Oh.

Sze: …in charge of research. He's very good, yeah.

Katz: TSMC is currently the leading foundry semiconductor supplier in the world.

Sze: That's right, over the 50 percent world semiconductor foundry in one company. And they developed the technologies more or less parallel to Intel.

Katz: They were closely associated with Philips in Europe as well, weren't they?

Sze: I don't know.. I don't think so. For example, Intel has been pushing for the 16 nanometer FinFET, okay.. TSMC, they already have the pilot of the 16 nanometer FinFET.

Katz: Ah-hah.

Sze: Yeah, so it's almost parallel. Very, very good, yeah. And I had a couple more students that became members of the National Academy of Engineering in the US also, so I think they did pretty well.

Katz: They were students in Taiwan or students at Stanford?

Sze: In Taiwan. And then become either foreign member or members of the National Academy of Engineering, yeah. They did pretty well, yeah <laughs>.

Katz: I'm aware that you also were a guest lecturer and/or a visiting professor at several other institutions, can you describe some of that work?

Sze: Oh yes. I like to teach so, for example I taught at Cambridge University in England..

Katz: One course, or a series, or a year's worth or two years..?

Sze: One semester. On semiconductor devices. In King's College.

Katz: Ah-hah.

Sze: They have a very fancy setup for the professors over there, at King's College. They have high table, that is when you dining, the professors sit higher than the students at the…high table.

<laughter>

Sze: Lots of interesting customs. For the.. coffee break also I like that, they have a very large common room for the professors from different departments. Someone told me they have had lots of Nobel prizes which were generated by discussions in that room <laughs>.

Katz: Oh, that's their equivalent of the Wagon Wheel here I guess, huh? <laughs>

Sze: Something very interesting at Cambridge. I taught at a few other places. I was a consulting professor, I was with Stanford for a few years with professor Nishi, we jointly offered a course on semiconductor devices.

Katz: I know you published quite a few books since 1969.

Sze: Yes.

Katz: …I presume you did as much publishing after your retirement from Bell Labs or more.

Sze: About the same, about the same. I completed about 20 book projects before I retired, now I have completed another 20 book projects after retiring. Among them I have seven authored books, nine edited books, and something like twenty-four contributed book,with one chapter or so.

Katz: I presume a lot of those are still in use by academia..?

Sze: The two most important ones are the third edition of my Physics of Semiconductor Devices book for the graduate student, and the third edition of Semiconductor Devices: Physics and Technology for the undergraduate student. Both sell pretty well, yeah. **M**y wife likes to see the royalty check every time... every six months, yeah.

Katz: So they old saying about "publish or perish" is maybe not applicable to you, you just publish to have fun, it looks like <laughs>.

Sze: It's fun, that's right, yes. And it's quite interesting.

Katz: Those books that you wrote, you said some of them are edited and some of them are total authored. Did you typically collaborate with other authors in the content? Or did you do these all on your own?

Sze: All the authored book I have... originally I was the single author, but eventually I had a co-author. For example, on the third edition, either the big book or small book, I have a co-author. On the edited books I most usually serve as a single editor, a few are co-edited.

Katz: Mm-hmm.

Sze: [For an edited book] you invite experts around the world and ask them each to write a chapter for a particular project.

Katz: Well here at the Computer History Museum we do have a reasonably extensive library of technology texts and other useful things, we'll have to see how much of it has the name Sze in it <laughs>.

Sze: If not I can donate more books to the Computer Museum. I brought one here, that's the first one.

Katz: I think we will be happy to put that in our library. You may be aware that we do make our archives available for scholarly research.

Sze: Wonderful. Okay, I will donate more books to the museum.

Katz: Not everything is exhibitable because there's only so much space available…but we do keep it available for scholarly research.

Sze: Okay.

Katz: And we do have a more extensive exhibit online, so we don't copy whole content of books for on-line access but we do abstracts and things like that.

Sze: Okay. This book, the big book, Physics of Semiconductor Devices, which is the fundamental for all the hardware for the computers. I think it has been extensively cited. It has been cited almost 24,000 times.

Katz: Oh.

Sze: That's quite a high number, yeah, for an engineering and applied science book.

Katz: I'd like to explore a little bit about your method of research a little bit. Can you describe some of the hard problems that you had to overcome in some of your research studies and accomplishments, And how you overcame them.

Sze: I think one thing is to check with my boss..

Katz: So you had political problems? <laughs>

Sze: No, the Bell Lab boss, actually has a mission is try to help the subordinate. So when I had the questions I always checked with them first, see what they think. And usually they come out with some very good answers. Usually, yeah. My first boss, Bob Ryder, was very, very helpful, a great device physicist. And another boss was George Smith, also very, very brilliant. In 1980 he set up the IEEE Electron Device Letters as the founding editor, and in 1970 he invented something with his boss, Bill Boyle, called a CCD, a charge-coupled device. He even got a Nobel prize in 2009 for that, yeah, and that's George Smith.

Katz: Original CCDs were meant to be.. computer memories also, possibly to replace cores or disc drives. They never made it as that, but they did pretty well as image sensors <laughs>.

Sze: Yeah it's as imaging sensor, for example, and many digital cameras use it.. and for some special applications. Yeah, the first men on the moon I guess had a CCD there with their camera.

Sze: So the boss is very important. And then I worked with many colleagues, actually trying to create synergy. Because each one of us had different ideas, when we work together we come up with some more brilliant ideas.

Katz: Was that.. done on your own initiative? Or was there some program in the Bell Labs environment to encourage it?

Sze: Bell encouraged people to collaborate, yeah.

Katz: In what method was that collaboration done? Were there assigned teams or..

Sze: No. We knocked on the door-- well we had a telephone book, that listed each person's specialties. So we just knockd the door and then asked whether he was free or not. Usually they were free, so you could ask questions and he would try to help you. It was a very free environment there. Actually at Bell Labs we weren't concern too much with patents, because almost all the patents were given out free. Bell Labs became so powerful they never worried about competition <laughs>, so we gave it free. I think the reason why Bell Lab, AT&T got in trouble eventually is because of their own success.

Katz: Indeed.

Sze: But at that time, it was a golden age when I was there, it was really very nice. I could work with anyone, talk to anyone and ask questions with anyone, and get help from many, many people.

Katz: But when you were doing all that, you must have encountered things that were, you know, some problems were harder to solve than others.

Sze: Yes.

Katz: Which were the hardest things you worked on?

Sze: I don't know, I don't remember anything that really make us stuck for too long, usually a short time problem. And... either I waited for a couple days or asked someone, I asked my boss. Probably most times I got the answer, at least a partial answer so I could pursue it from there.

Katz: Was all of the investigation done with your own knowledge and those of your internal colleagues? Or did you have to collaborate outside as well sometimes?

Sze: We always worked within Bell Labs, I did not collaborate outside Bell Labs. But Bell Labs had many, many divisions, imagine we had 30 thousand people in 20 different places, and with almost 8 major divisions. It was a very large organization, lots of talent there, yeah.

Katz: How did you choose with whom to work? <laughs>

Sze: I would talk to my boss, I'd say, "I need some expert to explain something," he'd say, "Okay, talk to Joe." And then I went to knock the door or call him first, and then they were all very helpful. We all tried to help-- I think the attitude of Bell Labs is try to be helpful, because usually they will return the favor at some time.

Katz: So I presume then you were asked to help others from time to time?

Sze: Oh yes, I know, I know.. I like to collaborate with many people, yeah. I only wrote one paper by myself, all co-authored.

Katz: Uh-huh. Of all those times when you were asked to help others, can you describe any of those helping hands that you offered that ended up in something useful?

Sze: I think so. For example... There was a new guy called... Wolfgang Fichtner from Austria. He was doing simulation, and he ran into some problems. So I said, "What would you like?" He said his computer's too slow. So we bought a very fast computer at that time, for him, to help him do the simulation. And..

Katz: What was he trying to simulate?

Sze: To simulate a three-dimensional MOSFET.

Katz: Oh.

Sze: Because usually it's two-dimensional. But when it becomes smaller the horizontal [longitudinal] field is almost the same as vertical [transverse] field, getting bigger, so it's not a regular channel device now, so it becomes three-dimensional. So he needed a much more powerful computer to simulate it.

Katz: So he's simulating electron mobility and things like that?

Sze: That's right, and the transport processes, yeah. You know, at the beginning of using computers it wasn't like this, it was a stack of cards. So my technician typed it for me and got all the cards ready to be sent to the computer center. When they fell, it threw the cards all over, so that’s <laughs>… you can never put them back, got to redo the whole thing.

Katz: Well we had some tricks we used to do: you put a number down in the comment field so you could sort cards if they got out of order...

Sze: Oh I see, good idea. We didn’t do that.

Katz: … And we also would draw a line with a magic marker, you know, on a diagonal..

Sze: Yes.

Katz: … and when you put them all together, if one of the marks is in the wrong place it shows up immediately.

Sze: Yes that’s another good idea, we didn’t do that, either. But this only happened once <laughs>.

Katz: Okay, well I like the idea that you collaborated a lot and that you got yourself involved in more than just your own research projects.

Sze: That’s right, yeah it’s very helpful with the other colleagues... really helpful. I had many great colleagues at Bell Labs.

Katz: Are you still in contact with many of them?

Sze: Some of them, yes. Actually yesterday I saw quite a few at the ISSCC. And of course they are getting old, but they’re still in good health.

Katz: That’s good to hear.

Katz: Let’s go again a little bit into your post-Bell Labs period as an academician.

Sze: Okay.

Katz: When you are teaching courses, do you have a prepared syllabus or content that you like to give?

Sze: Yes.

Katz: Or is that kind of free-form, or what?

Sze: I think I'm probably the only professor who only uses his own book, I never use other people's books. I teach the graduate students with my big book and integrate it with my small book. Also I combine a few more books to form the lecture notes for myself, yes. You see, between the edited and the other books I have a wonderful system. I can combine them or just use a few chapters from a book, yeah.

Katz: Do you teach more undergraduate or more graduate level?

Sze: Most are graduate level, I use my big book, the first edition, second and third editions for different times.

Katz: So by the time you get the students they're already on the track that they ought to be. You're not trying to teach them one direction or another, they've found their direction.

Sze: But I did teach some undergraduates. Actually I think teaching undergrads is harder. The undergraduate class is bigger. In Taiwan I have a hundred, two hundred students per class. But it's fun.

Katz: I've done a little teaching myself as an adjunct professor… just a one-time lecturer from time to time, and I find the undergraduates more challenging…and therefore sometimes more rewarding <laughs>.

Sze: Yes. Also I like the old-fashioned way of teaching using the blackboard. Now they use PowerPoint…

Katz: Yeah.

Sze: …and I don't like that really. At Stanford you have to use the PowerPoint, you take your USB to the classroom, put it into the machine and then just start a projection. I don't know if that's a good idea or not.

Katz: Have you participated in any of the new online university activities?

Sze: Yes, I'm offering a course-- this year, I'm going to offer a course called the MOOC, Massive Open Online Course ... an internet course on semiconductor device physics. That one is 100 percent PowerPoint, I have to prepare something like 300 displays for a 10-hour course. So it's about 30 pages per hour.

Katz: Do you make your own PowerPoints or do you have an assistant who helps?

Sze: Someone will do it for me, but I have to prepare for the original, the first draft. It's fun, I'm going to try this year, I never did before, first time. I know it's very popular for Stanford University, they offer quite a few..

Katz: Stanford is among the leaders in that.

Sze: Yeah, they like to offer the so-called MOOC course.

Katz: Right. Okay, are you confining all of your work now to device physics? Or have you branched out into any other technologies?

Sze: Where I work in the university in Taiwan I served for six years as a director of one of the organizations they call the "Microelectronics and Information Systems Research Center," which is one of the centers in the university. And also I was director of the Nano-electronic Device Laboratories there for six years. So as a manager you are mainly concerned to hire people and to control of budget, that's a different... <laughs> different way of operation. But still, I like to work with students on different projects.

Katz: The projects all are in device physics, electrons and holes and things like that?

Sze: For the past 10 years, my main project is working with other professors on non-volatile memory. I think that's since... yeah, it's within 10 years I coauthored about a hundred papers on non-volatile memory alone.

Katz: Are you sticking with silicon or are you moving over..?

Sze: No, we moved to different materials.

Katz: Will you be looking at phase-change memories?

Sze: No, we are mainly concerned with RRAM [Resistive Random-Access Memory]. Actually that one has a good chance of success, for example yesterday in the ISSCC I looked over the program, and found there are three papers on RRAM, they are reaching 32 gigabit [capacities].

Katz: Can you give us a two-minute summary of what is that?

Sze: The RRAM is bias dependent differently, okay? You can either increase the resistance or decrease the resistance, so that forms the binary zero or one. And the mechanism is still not clear, we don't know exactly how RRAM operates, but it seems it works very fast, having very small —cell size, very high density and high endurance also.

Katz: Yeah.

Sze: We don't know the mechanism for that..

Katz: <laughs> So I guess we don't know yet how scalable it might be.

Sze: We don't know. But, RRAM is the only non-volatile solid-state memory proposed ahead of the floating-gate. You see the RRAM, the first one was proposed in 1961.

Katz: Wow.

Sze: But then people gave it up because they don't understand how it's done in physics. But now it has become a renewed effort, and many, many universities and institutes are working on RRAM.

Katz: Why is it becoming renewed now? Because of its density implications?

Sze: Because of high density, high speed, and high.. I guess.. endurance, it has been switched [back and] forth many, many times. Even [though] we don't know exactly what happens inside. Looks very interesting. And there are others: spin torque transfer MRAM, we have FRAM, ferroelectric, then we have so many others. But this one, RRAM, seems to have a good chance of success. If you are looking for a unified, universal memory..

Katz: Yes, that's the ... holy grail of memory.

Sze: Yeah, holy grail of non-volatile memory. Maybe RRAM, I don't know. But it will take many years, to replace floating-gate will take many, many years. For example, it took almost 40 years.. yeah, 40, 45 years for the vacuum tube to be replaced by the bipolar transistor. And it took almost about 20 or 25 years for the MOSFET to replace the bipolar, okay more or less. And now to replace floating-gate I think it will take another 20 years, maybe more. Because floating-gate is already reaching one terabyte now, with multi-level-cell and multi-layer-stacking using TSV [through silicon via]. To replace that it's not that easy, really, yeah.

Katz: And for that matter, there are still people making core memories for space applications.

Sze: Yeah but it's only a very niche project.

Katz: Yeah.

Sze: Also, yesterday, a few invited speakers said that it's almost impossible to replace CMOS. If that is the case, then all this non-volatile memory has to be compatible with CMOS process, and the floating-gate is a perfect one.

Katz: Why is it impossible to replace CMOS?

Sze: Because CMOS is already reaching the-- we already made a four nanometer MOSFET, they are being made, it's just not yet mass produced…

Katz: So we're three steps ahead on the... Moore's Law curve.

Sze: Yeah but to replace four nanometers [CMOS], will be almost impossible. It's even smaller than carbon nano tubes. The same dimensions, so it's very hard to replace that, yeah. You have to be many, many times (e.g. 10 times) better than the existing technology to replace it, not just 10 percent or 20 percent; not good enough.

Katz: Are you familiar with or working on the quantum computing concept?

Sze: Many people say that it's useless.

Katz: Yeah, many say it's useless and many say maybe it's not <laughs>.

Sze: Yeah maybe it's not, yes. It's much easier to say it can work compared with saying it doesn't work, because the negative is very hard to prove. Almost impossible to prove. But MOSFET is so powerful, to replace MOSFET is not very easy. Even to replace floating-gate is not that easy, because it's always easy to improve the current status by making some novel changes of the similar technology. It's hard to replace.. because a large infrastructure is already there.

Katz: Well so it's good to see that you've been continuing to be active and on the forefront of new technology.

Sze: And doing research and doing some teaching.

Katz: And you continue to publish books I presume, too.

Sze: Well I... collaborate, I find a good young author to collaborate with. I do the planning and make some major suggestions, for example the format or the layout of the book. And the young author will do most of the reading of the literatures...

Katz: Are those authors typically from academia?

Sze: Oh yeah, typically they are professors, also-- for example my third edition co-author was Kwok Ng, he used to be in my group, a very nice engineer scientist. He spent five, six years on it, lots of work to realize it.

Katz: We're getting close to the end of our conversation here. I'm wondering now, can you just describe of all the things you've worked on, do any of them stand out as being the most rewarding? The most fun to work on or the most satisfying to know that they had a large impact in the world?

Sze: Of course the non-volatile memory is one. And writing books, also fun. It's hard work but it's always I think very rewarding when you see the bound book. It is tangible.

Katz: …a lot more tangible than an electron or a hole <laughs>.

Sze: And also when you see it's well-received as a textbook, and well-cited in technical papers, that makes me very happy. I don't know any publication in our field being cited more than my book, it's over 24 thousand times. That's a lot, typically a paper being cited a hundred times is considered high, a thousand times is very rare, 24 thousand is almost... impossible <laughs>.

Katz: Well let me ask the opposite side of the question then, throughout your career are there any events or decisions that you made that you wish were different, when you look back at them from today's perspective?

Sze: Let me see .. not much to regret really, I think I was very lucky because my professor suggested Bell Labs, and Bell Lab was indeed very, very good. Oh yes, around 1987-- '86, you know the announcement of divestiture of AT&T okay? That is they were going to break up AT&T into eight or nine parts, okay. And then Bell Labs remaining with the existing AT&T, and then Bell Labs shifting to Lucent Technology. I was not happy after that, because the environment started to change. You got a direction of exactly what to do, It was different from the original Bell Labs...

Katz: Right, every entity had to show its own worth <laughs>.

Sze: That's right, you had to show you are doing something really useful for Lucent. That was around the 1986, '87. But at that time I was still too young, I could not retire. Then two years later they made the announcement called... "Five, five, fifteen."

Katz: Yeah.

Sze: They add five years to your years of age, five years to your service, and they give you 15 percent more. So I was the first one who applied for retirement. I retired from Bell Labs when I had not reached 55. Then I talked to one of my students in Chiao Tung University, I said, "I'd like to come over to teach." And it's Mister C.Y. Chang, he was my first PhD student, At that time he was in charge of R and D at the university, later on he become the president of the university for six years. And he invited me over and so I said, "Okay, I'm going to retire from Bell Labs and join the faculty." So from 1990 until now I've been with the university there.

Katz: Have you been teaching pretty much full-time the whole time?

Sze: At the beginning yes, at the beginning I was teaching two courses and also in charge of one research institute. And I'm sort of semi-retired since 2004, so right now I'm doing whatever I like to do and also preparing for this internet course. And I'm still involved with a book project.

Katz: Is that the internet course that is through Stanford?

Sze: No through our university, it's not from Stanford. Stanford has so many MOOC, they don't need this one.

Katz: I see. Okay, so do you still do guest lecturing outside?

Sze: Oh yes, each year I try to give one lecture... three weeks at different universities. For example on mainland China, I've been there 11 times already, I pick out a place I like to go, and. my wife likes to go, and I find a university nearby. Then I write a letter to the president of that university and say, "I'm coming over, free of charge, except you have to pay for our traveling expenses." And then I teach three weeks, yeah.

Katz: When you teach those courses, you teach it in Mandarin? Or in Taiwanese, or English or what?

Sze: The PowerPoint is in English, but I talk in Mandarin. It's a hybrid language, a hybrid language, because all the terminology I don't translate. Because China and Taiwan have different translations for the terminology, I don't bother, I use English directly for the terminology.

Katz: Are the books you publish in English or in other languages?

Sze: They're all English. But I do have Chinese translations both in Taiwan and in China, I had.. Russian translations, Japanese translations, Korean translations, Spanish translations and Italian translations. Not any more, I think in the past 15 years there's no translation, needed for the European countries.. they all decided to use English.

Katz: Well it's become the lingua franca of technology.

Sze: Yeah that's the technical language now. English so powerful you don't need to translate. The only places that need translation still are Russia and China. I don't know why, their English must be poor <laughs>.. so they just have to translate it for the students. Oh also Japan, Japan yes.

Katz: In your role as a senior professor, I presume you're advising more junior professors and students..

Sze: Oh yes, mm-hmm.

Katz: What advice would you give to our listening audience.. for maybe an undergraduate, what should they be doing or even before university, what should people be doing to prepare themselves for research and.a. productive inventing career?

Sze: I have some suggestions, I think the first one, probably the most important, is be diligent. You cannot be very lazy or not hard working; be diligent, that's important I think. For example when I worked on my book I spent 3000 hours on it, that is around 10 hours per day for a whole year. It's very hard work, diligent, yeah. The second one.. I would think would be... cooperating, because one plus one, if you create synergy it's much larger than two. So collaborating with other people is very helpful, I like to collaborate with people and create lots of joint authorship. And thirdly, I think, be curious, that is try to explore new possibilities and maybe search for new frontiers. Yeah always be curious, don't take things for granted.. and then you may come up with something, like the floating gate memory, it's just we were curious about whether there's a replacement for magnetic-core memory or not. Most people said no, you see I talked to a colleague in Bell Labs he said, "It's impossible to have semiconductor memory," I said, "Why?" He said, "Because the recombination times are only a millisecond, how can you store something for years?" So you see, so if you're curious you will come up with something that might be very useful. There are many things we cannot change; your parents you can't change, right? The environment you cannot change, because if you are living in Syria you are in trouble, because..

Katz: <laughs>

Sze: And also… you need some luck, you see I had my professor who recommended that I go to Bell Labs. That's something I could not control, but he recommended I go there, it happened to be the right place. But the diligence I think I can control…cooperating I think I can control, and curiosity I can also. So I thought maybe the students can consider these as useful suggestions.

Katz: Well those are very good advice.

Sze: Thank you, sir.

Katz: People told me similar things early in my life too <laughs>, yeah.

Sze: I tried to be diligent when I worked at Bell Labs, I always worked very hard. For example, the first three, four years at Bell Labs I went there every weekend, Saturday and Sunday, no exceptions.

Katz: You must have been really popular at home.

<laughter>

Sze: My wife was not very happy of course, but… she understood that I have to work hard in order to establish myself professionally. I think diligence is an important ingredient. And I like to help people, and many people actually return their favor very soon. I don't expect it but they do... Helping people is very good. Collaborating and being curious are also very helpful.

Katz: Okay, well before we wind up I want to come back to one of the things you said very early in our conversation, that you had this idea and you brought it to your boss, who said it would never be worth anything. And now you've demonstrated that it's worth more than all other semiconductor memory combined... <laughs>

Sze: I believe the floating gate memory is the second most important semiconductor device, after the transistor, for our global electronic information industry.

Katz: I believe that may be true. Has your boss every acknowledged that?

Sze: No, he passed away many, many years ago…

Katz: So he never got to see that he was wrong <laughs>.

Sze: You see the whole explosion of the non-volatile memory began around the late1990s, and he passed away around that time. It's too bad, didn't get a chance to tell him.

<laughter>

Sze: But he was a good boss, he was very helpful. He helped me with my book and he gave me lots of help on that, and gave me some guidance, and he gave me the freedom to do whatever project I wanted to do.

Katz: Okay, well I think we'll wind up at this point. And I appreciate your time with us.

Sze: Thank you.

END OF INTERVIEW

