Oral History of Charles H. Sie

Interviewed by:
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Dr. Charles H. Sie, November 16, 2012

Jeff Katz: We're here in Rolling Hills, California on November 16th, 2012. I'm going to be interviewing Dr. Charles Sie. The interviewer is Jeff Katz. So, good afternoon Dr. Sie. Let's start into the discussion with a little bit of information about your early life.

Charles H. Sie: Sure.

Katz: Where were you born and grew up and where did you go to school?

Sie: I was born in Shanghai, China. In 1949 when the communists came to liberate Shanghai we got on the refugee boat and we went to Taiwan, because my father was working for the nationalist government. So naturally we had to run away from the communists. Then we were in Taiwan for one year. My father served in the Diplomatic Corps of the nationalist government. We came to America when I was 15 years old.

Katz: Where did you land in America?

Sie: New York. I went through high school in New York and through college in New York. I went to Manhattan College in the Bronx.

Katz: Getting a degree in what?

Sie: BSEE, Electric Engineer.

Katz: Interesting. Okay, after your college, I know you've had more education than that; what other schools did you attend?

Sie: Then I went to work for RCA and I went to school at night. I got my MSEE at Drexel University in Philadelphia. Then I got my Ph.D. in 1969 at Iowa State University in Ames, Iowa.

Katz: Well, let's go back to your early time in New York City. What made you decide to become an EE?

Sie: Ah, it's an old story. When I was a young boy in China, you know, seven, eight years old, I was always fascinated by radio. You know, how could you listen to a sound of something and you don't see anything? I was intrigued by that. In those days, there were these kits, you know, the crystal radio kits. You know, attach a crystal, a crystal set and you could…

Katz: I'm very familiar with it. I made one myself as a boy.

Sie: Oh yeah, and I was fascinated by this, you know, radio. But I think later on I decided [to be] an electrical engineer when I was in New York, and had graduated from high school. At that time, you know, our family was not that well to do, because the communists took over China and working for the nationalist government wasn't that well paid. So our parents told us "Go study something you could make a living on." And we all thought an electrical engineer probably was the best way to go. You could get a job, right?

Katz: Yes, you could. But you could get a job as a lawyer or a doctor or a teacher too.

Sie: Oh no, no, no. At that time, you know, we were immigrants, right? Our language skill was not that good. In engineering you deal more with equations and numbers…

Katz: Indeed.

Sie: …and that's much easier for us.

Katz: Were there any particular people in your early boyhood or high school life that influenced you toward electrical engineering?

Sie: Yeah, you know, I went to a Catholic school. There was a Brother Albert; he was a physics teacher. He, I think, had quite a bit of influence on me to be interested in physical things instead of liberal arts stuff. But of course the limitation of my language skill played into it, right?

Katz: Very interesting. All right, so now let's come back to after you graduated from Manhattan College with an EE degree you said you went to work for RCA.

Sie: Yes.

Katz: What were you doing for them?

Sie: Oh at that time I went to RCA is because I was on the immigrant visa, you know, and in 1957 is just after the Sputnik, the Russians launched the Sputnik, and the US government was really ratcheting up their work in engineering, electrical engineering, in telecommunication, in satellite [development] to catch up, right? So, at that time, RCA was willing to sponsor me to get a green card. So, I grabbed that job right away for the sake of that green card. I started to work at RCA actually on circuit design. In those days, there was a military contract to make a time division multiplex system and use pulse-amplitude modulations. I also worked on pulse-code modulators.

Katz: What were those devices going to be used in; in what kind of end equipment?

Sie: The end equipment for the Army was time division multiplexing for Fort Monmouth. They used it for Army communication purposes for the field. But the pulse-code modulation stuff we worked on; we did not know the application too much, because it was for National Security Agency.

Katz: I see. They don't tell you what they're going to do with it.

Sie: But they just want a Compander modulator. The interesting thing is this; in late '50s or early '60s, when you designed a multiplex system, there were no modules, no logic modules, right? You started from scratch.

Katz: Raw transistors.

Sie: Raw transistors <*laughs*> and there were no flip-flops. So, I actually had the fortune to design flip-flops with transistors, resistors, capacitors, and inductors. I had to design flip-flops, shift registers, one-shots, and AND Gates, OR Gates; all that kind of stuff from transistors. In those days, a good logic transistor, I still can remember, was 2N501; that's a Philco part. It was 20 megahertz; oh that's big stuff. Then RCA. I still remember there was like a 2N404; those were for audio purposes. But oh, in those days we designed those things, right? We were not even sure it was binary, because the transistors were so expensive we could save so much money by going to ternary. I actually have designed ternary flip-flops. But at the end we did not use it because the logic was a little bit complicated.

Katz: Indeed.

Sie: But we tried. I think nowadays I if explain it to you or to the young people, the modern day people, they wouldn't be able to envision [our work] in those days, in '57 to early '60s. You know what I'm saying. It was a [time of] transition from the [vacuum] tube to transistors; the integrated circuit hadn't come in yet.

Katz: Yes, it wasn't until 1960 or so that computers were doing digital circuits based on transistors. And before that they were used for radios.

Sie: Yes. And I still remember the transition between discrete transistor and integrated circuit. I still remember a project we worked on for Fort Monmouth. Some people may remember they were called micro rack and micro pack.

Katz: Micro rack and micro pack.

Sie: Yes. What we were trying to do was using [a ceramic] chip, you know, a transistor on the chip, and stack them up, and resistors on the chip, like a squirrel cage with the wire connecting on each side like a cube; and that was sort of the transition. We could miniaturize the circuit design before [there were] integrated circuits.

Katz: Right.

Sie: You see what I'm saying?

Katz: Indeed, yes.

Sie: And all of those days I still remember the test equipment we used in the lab was all decks, right, the decks had those boxes, I still remember, elongated boxes; these were the modules, the flip-flop module, AND Gate module. You had a big rack and put them together, wire them together.

Katz: Right, with the back plane.

Sie: With the back plane. As I look back, you know, it was quite an experience for me. I guess nowadays, you get [an] electrical engineer, you tell him to design a flip-flop, and he'll probably tell you to go fly a kite, right?

Katz: Well, there's no need to nowadays. Okay, so you worked there for a number of years, you then worked elsewhere. What was your next move in your career?

Sie: Then what happened is I started to understand "Oh this computer is interesting stuff." I did not work directly on computers but I worked on those circuits that were used in computers, right? So, at that time, IBM Watson Research Center was looking for a circuit designer. The circuit was for thin film memories. They wanted to make [a] read-only memory using— it was really not thin film; it was a thick film memory, for the atom machine, [a] very fast read-only memory. And they needed someone to design the circuit, you know, the driver for the sense circuit. I had experience in those areas, so I went to work for them and designed the circuits for read-only memory. But my interest was in more than the circuits. I started to [become] interested in the memory elements.

Katz: Actual memory device.

Sie: The device.

Katz: The part that stored the information.

Sie: That's right, because my curiosity really led me to try to work in that area. At that time, you know, thin film memory were the big thing; that was before semiconductor memories.

Katz: Yes.

Sie: And thin film memory, two magnetic, nickel/iron films.

Katz: Well, there had been magnetic core memories before that…

Sie: That's right.

Katz: …but they were notoriously hard to build but they were also— they took up a lot of space.

Sie: That's right.

Katz: And to make them smaller and therefore maybe faster or more reliable, people were experimenting with other techniques like thin film.

Sie: Right. The thin film really was the transition between core and semiconductor, you see.

Katz: Yes.

Sie: At that time, we thought that thin film [was] going to take over the world. What happened was the nickel-iron film read-only memory I was working on was really— it had two films, the nickel-iron and the cobalt-iron film. The cobalt-iron is a higher threshold device and we stored…

Katz: Higher threshold?

Sie: It reaches the HC, you know, it's a higher— it takes more current to switch.

Katz: Okay.

Sie: So, that cobalt/iron film was used as the storage element; you write into it with a logic current and you read out the information in the cobalt/iron film with the nickel/iron film; that's thin film. So we called that a thick film memory. Because of my interest, I got into the switching mechanism of both the thick film and thin film. And this is the switch of the spin or the switching of the wall of the domain; there's two type of switching in there.

Katz: These are still magnetic?

Sie: All magnetic, yes, right. So, I got involved into that area, you know, starting from the circuit [and] into the…

Katz: Right into the physics.

Sie: …physics of this. It really got me excited. And that's what really led me to go to Iowa State.

Katz: I see. How long were you at IBM then?

Sie: Three years working on that stuff. Then what happened was, at that time in IBM, you know, that was before semiconductors; thin film [was] going to take over the world. There were a large group of people working at Yorktown on thin film magnetic memory, and a large percentage of these engineers or scientists all came from Iowa State and…

Katz: Those were the scientists at IBM?

Sie: Yes, and they were also students of this Professor Pohm; he's sort of pioneer.

Katz: Can you spell Professor Pohm's name?

Sie: P-O-H-M.

Katz: Thank you.

Sie: He had been at Univac and he was the early pioneer in this area.

Katz: I know that Univac had used thin film memories back in the late 1950s and early '60s.

Sie: Yes, that's right. He went to Iowa State to become a professor and focus on thin film memory. He had a program called "Industrial Affiliates Program". That program was supported by IBM, Univac, Control Data, all these computer companies; his affiliates program sponsored graduate students and I was one of them oh, also including Fairchild.

Katz: So, Fairchild [Semiconductor] was already interested, at that point, in thin film memory?

Sie: They were interested, yes. I mean, this group of people was interested in memory technology. Now, what happened is semiconductor memory had just came on board.

Katz: Was it roughly late '60s, early '70s when Intel was formed?

Sie: Right, right, yes. These are 1k DRAMs.

Katz: But there had been, before that, into the mid-‘60s, there had been also the beginnings of semiconductor memory basically made out of flip-flops.

Sie: Flip-flops, that’s right.

Katz: And we called them— now we call them static RAMs…

Sie: Yes.

Katz: …but they were only 16 [or 64] flip-flips together.

Sie: The static RAM; they’re all flip-flops.

Katz: Yes.

Sie: Right, right. Then what happened was, you know, there are other companies working on DRAM like MOS Tech, AMI, [and] of course, Intel and Fairchild. One of the issues that Professor Pohm started to stress was non-volatility. He said magnetic film is non-volatile but all the semiconductor devices, they’re volatile, right?

Katz: Correct.

Sie: So, after I took my course work and I thought I was going to— because my [thin film] work at IBM right, I had the software to solve the Landau-Lifshitz equation, the Landau-Lifshitz equation for switching for [damping]. I had samples ready. I had the equations ready. I thought I could just take that stuff and package into, and form my Ph.D. thesis, right? Then I went to Professor Pohm and I told him “I’m going to do something about modeling the [thin film] switching mechanism for my dissertation.” And he came back with an interesting answer. He said “Charlie, you’re not going to do that to me. You’ve got to do something new.”

Katz: The nature of a Ph.D.; you have to forge new territory.

Sie: Yes. He said “Charlie, I would like you to look into non-volatile memory.” You see what I’m saying? Then, at that time, you know, besides thin film memory, there was no other non-volatile memory, right?

So I started to look into that. And then I started to understand that there was some writing about the crystalline phase versus the amorphous phase of some materials, and especially I read the writing of one guy by the name of Ray Hilton from Texas Instruments. Like I was telling you, he's still doing this work today, though that was in 1967-68. He was working for TI, Texas Instruments, and he was using chalcogenide glass…

Katz: I think you better spell that word for our transcriber.

Sie: C-H-A-L-[C-O]-G-E-N-I-D-E.

Katz: Thank you.

Sie: And that means anything consists of element like tellurium sulfur or selenium, you know, in that [periodic table] column. So he was using this chalcogenide [glass] for a military application, for missiles; for infrared seeking missiles, you need windows, right? He was using that. And at that time I heard about Stan Ovshinsky, who was working on some kind of chalcogenide stuff, but not much stuff was published. It was kind of very proprietary.

Katz: Ovshinsky was very secretive, as I recall.

Sie: He had to protect his [ideas]— because he was afraid to be eaten up by the big guys. So, I had nothing to go on except that I had read this Ray Hilton's publication.

Katz: Will you spell Hilton's last name?

Sie: H-I-L-T-O-N.

Katz: Like a hotel.

Sie: Like a hotel, right. So he was the only— oh, wait a minute. I should go back a little, once more. I [had] read somewhere [that] in Bell Labs they did some work on organic film; this was before I got onto Ray Hilton, now. Some organic film had resistance change ; there was some work by this guy, I believe it was Dave Pearson at Bell Labs. At that time, I was at the lab. They had this organic stuff, Epon 820 lying around, that's a Shell Chemicals, organic stuff. So I spun some on to a glass with a metal background, and tried to make a switch out of it. And it worked, but not for too long.

Katz: Not a very high endurance. How many cycles could you get?

Katz: Yeah, five or six cycles and then it's gone. I showed it to my professor and he said "Oh you have not demonstrated feasibility now." <*laughs*> That's how I came to this Ray Hilton's stuff. He was working on this germanium tellurium eutectics with arsenic added. With the arsenic they call it glassmaker. So I started to work on that material. Then I found out that the material makes a pretty interesting switch, [a] memory switch, you know; I was working on memory.

Katz: With unlimited endurance; as many cycles as you need?

Sie: Oh no, no, no. But if this [would] switch for me for, you know, [a] couple hours I would be happy. You see what I'm saying? You know, you could switch it 100 times or 1,000 times, I'd be happy; [but] not 5, 6 times. Now, not as a threshold switch; as a memory switch.

Katz: Right.

Sie: You know, you crystallize, then you reset, you know what I mean?

Katz: So it was completely reversible.

Sie: Yes, completely [is] the word, yes be careful [with] completely. Now, what happened is my professor told me "You have to demonstrate it, right, not just in bulk material; you have to make a thin film [memory] device." Do you see what I'm saying?

Katz: Okay.

Sie: So, how would I make thin film device? At that particular lab where I was studying they made magnetic film all the time, so they had a vacuum set up, a bell jar with thermal set up for thermal evaporation, right? So, what I did was, of course, first you have to make the raw material, the germanium arsenic tellurium stuff; you have to initially put in the quartz tube, right? I think I heated it up to something close to 1,000 degrees and you rock [ph?] it for 24 hours. I only [learned this because I had] read up in somebody else's work. Then after you heat it, you take it out and you quench it just in the air, in room temperature. And what happened; it became amorphous. You know, all those three elements get together and became amorphous ingots.

Katz: Like glass.

Sie: Like glass, right. Then I had to evaporate it, right? So, what did I do? I thought to crush it, you know, crush the material into powder then put it in a boat to evaporate it in a vacuum, right?

Now, what happened is oh there's another long story, I never had [previous] experience with vacuum evaporation, right? I just read about it. I had to evaporate a chalcogenide film. I thought we should evaporate something about 5,000 angstrom to one micron; that's the thickness I was shooting for. But while, I was setting up to [get] ready for evaporation, I saw hey, some of the components in the thermal heater were not holding on right. So, I said "Oh let's hold it right during the evaporation." So, I used Scotch tape to tape them on.

Katz: That was inside the vacuum bell?

Sie: I didn't know any better, right? So, I pumped out and the moment I pumped it out this plastic Scotch tape outgassed to the whole system, including the pump, the bell jar. This vacuum technician came over to talk to me. He said "Charlie, what the hell are you doing?" He said "You never put this stuff in a vacuum jar." I said "I didn't know." Then the whole lab was shook up. So they said "Charlie, you get to clean it up." So, I spent about two weeks cleaning up the bell jar, the vacuum system. I It was quite a job. And I also learned that in order to clean up a vacuum system you cannot use Ajax or any of that stuff. You have to use Bon Ami because that was the only cleaner that was pure eggshell with no chemicals in there. I remember till this day Bon Ami is the good stuff; no chemicals, you know.

Katz: Very interesting.

Sie: So, then I learned my lesson. for the second trial I was using, I remember now, it's a molybdenum boat, you know, little boat for thermal, you know, with kind of both sides hooked up to a voltage source, Then you heat it up; the boat, right, you evaporate [the contents]. It's a baffle boat, a container, right, for evaporation. But I was using tungsten probe. I thought "If I get a tungsten boat that will be very nice," right? So, I get a tungsten boat and start to crank up. You know what happened? All these powders got all stuck onto the boat. <*laughs*> So my second trial was a big failure.

Katz: Okay.

Sie: Then I talked to some vacuum technicians who said "Charlie, maybe you should try molybdenum boat. But [if] you're so worried about the interaction between the material and the boat, one little trick we do is to take some alumina powders, suspension powders, and spread [them] on the molybdenum boat so it would not be reactive to your chalcogenide material." You see what I'm saying?

Katz: Okay.

Sie: So, I took this molybdenum boat with alumina spread around, and let it outgas. Then [I] put in the chalcogenide material; then also you crank up the powder very quickly, [and] in like 15, 20 seconds everything is evaporated. And that was my first successful film. I tried a few times but maybe fourth or fifth time…

Katz: And with that film you could actually then have a process which was reversible?

Sie: No. This is just the first step; making the film.

Katz: Oh, I see.

Sie: Then what I had to do, my professor said "Charlie you have to make array, you know, you make this film. How you're going to use it," right? So the next step [was] I actually evaporated aluminum [wires] using a mask, opening mask [slits] for aluminum like two mil wire, you know. And I evaporated aluminum onto a microscope glass with the aluminum [wires] lying on it, right? Then I evaporate on the chalcogenide. Then I turned the mask 90 degrees. You see what I'm saying? Then evaporate aluminum again. Then I had an orthogonal array [of wires with the chalcogenide material film in between.

Katz: Right.

Sie: Right. Then I tried to switch the material at the intersection [of two wires].

Katz: So the material was between the two layers you had created that were orthogonal?

Sie: Two layers that were orthogonal; right. So the materials in between you have one wire going this way, one wire going that— switching that [material where they crossed] in the middle. Do you see what I'm saying? But then if you have a pure resistive array it would not work, because of the sneak paths. You see you have other paths because [there was] pure resistance at the intersection. So I had to make a diode array to demonstrate [that] you can make a memory array, because you need an isolation element [for each memory "cell"]. The isolation element is the diode.

Katz: Okay.

Sie: But how was I going to make a diode array? I had no capability to make a diode array. Then we got a transistor in a T05 can from Fairchild.

Katz: How did you get that? Just go out and buy it?

Sie: No, no. Well, my professor was a buddy of Gordon Moore and Bob Noyce, you know, they both knew each other. So, I got a T05 can. Then what happened is that I just used the emitter to base junction as a diode. Do you see what I'm saying?

Katz: That's what the emitter-base junction is, a diode.

Sie: Yes. So, what I did was took the T05 can, opened it up, right, and evaporated chalcogenide film on it on the base. Then I had a probe on top, so I had a device with the memory element and the diode in series with the switches. Do you see what I mean? I did not make a whole array but I just made one element with a diode and chalcogenide material in series and showed it could switch from a high resistance state to a low resistance [state], you know, it could go…

Katz: And reverse it back.

Sie: Reverse it back. And that's how I wrote my thesis.

Katz: So, when was that thesis written?

Sie: Oh, it's between '68 and '69, yeah.

Katz: Which predates other non-volatile memories…

Sie: Yes, yes.

Katz: …except for magnetic ones.

Sie: Right. But now [as] I look back, you'd think it was trivial. But in those days it was hard because my knowledge in that kind of area was limited and I had to learn everything by doing, by *doing*.

Katz: Right. You had to learn the chemistry, the material science and the physics as well as the EE.

Sie: Right, right. Right. I tried to learn as little as possible because I want to get the hell out of there. Because at that time I had a wife and three kids, living on something like five, six hundred dollars a month.

Katz: A graduate student's stipend, yes. All right, so that's very interesting. Having gotten that experiment to work, what did you do with it? And I presume they awarded you your Ph.D.

Sie: Yes.

Katz: Then what happened in your life?

Sie: Then I was looking for a job, right? Of course, I was on educational leave from IBM. Yorktown wanted me to go back to work there at IBM, but at that time I met Stan Ovshinsky, from Energy Conversion Devices. He said "Charlie, you should come work for me." And also he actually offered me some stock from the Energy Conversion Devices company. I could never get that at IBM, right? So, I went to work for Stan, because he was very personable and I thought I could learn something there when I worked for him. But also there's another story related to that. At that time he was in Detroit, right?

Katz: Yes.

Sie: And so, my wife was also studying at Iowa State University; she was getting her Ph.D. in Educational Statistics. She was one year behind me. So I negotiated with Stan saying every weekend I get to go back to Ames, Iowa.

Katz: That makes sense.

Sie: Yes. So, with a wife and three kids there, I went back there every weekend. And that's how sort of I did this work to make that video [of the chalcodenide changing state].

Katz: Tell us about the video.

Sie: Yeah, about the video.

Katz: You were going back to Ames after your Ph.D.; you were working for Energy Conversion Devices, and you showed up on the weekends in Iowa.

Sie: There was a graduate student there by the name of Ron Uttecht from IBM. He and I became good friends. We say "Let's do something really see how the hell the damn thing works."

He's [now] in Burlington, Vermont.

Katz: All right.

Sie: So, we talked about that. But you know, to make that movie to show the physical characteristics you needed a lot of equipment, right? We went to the Ames Laboratory in Iowa State University; that's a very well equipped laboratory. I don't know if you know it or not, Ames Laboratory is the lab that refined the uranium for the Manhattan Project. So, they have lots of equipment. So, we went to that laboratory. At least Ron and I [went] on weekends— we said "We must be able to see this switching, with two probes on top of a piece of glass; see how the transition occurs." Then we found out there was a filament growth coming out from the positive side always going to the negative side.

Katz: You could see the filament?

Sie: You could see the filament. That's the [video] stuff I put on YouTube. You could see the filament growing. Oh, before the growing of [the] filament there was a flash on the surface of the piece of material between the two probes. You know what I'm saying?

Katz: Oh.

Sie: That, I believe, is the threshold switching but nowadays there's new interpretation of what I saw just recently. First you see the flash. Then the filament grows from the positive side to the negative side; that is driven with a voltage source. Now, if we change to a current source between the two probes and you just have a very narrow short current pulse, you will erase that filament back to the high resistance state.

Katz: That's the amorphous state.

Sie: [The] high resistance state is the amorphous state. The crystalline filament is the low resistance state, yes.

Katz: Right.

Sie: But the interesting thing is this flash, right? We could never explain that. But just recently, you know, 2011, 2012 now, right, I read an article published at the University of Pennsylvania; they're doing this work and they say they've discovered this so-called "Electric Wind."

. But that's the flash and they tried to explain that phenomenon. And that's the stuff we saw in 1969.

Katz: Very interesting.

Sie: They explained to people saying "This wind is necessary to make the material more amorphous." And it sort of fits what we saw. The initial flash, you could not see filament grow before the initial flash. The initial flash was to change the material to a more amorphous state before you could grow the filament.

Katz: Hm.

Sie: And [after reading] that [article] I thought I [should] put this [old video] thing on YouTube, because since 20, 30 years I wasn't working on this phase-change memory. Then about two or three years ago I read in a science magazine they say phase-change memory is the future for never [running] out of memory. I had a total surprise. I said "Holy smoke, the stuff I did in 1969 [is] going to be the future of memory."

Katz: What makes it the future now when it wasn't so much the future 30 or 40 years ago?

Sie: I think it's because, everybody talks about flash memory [nowadays], right? These are basically EPROMs, right?

Katz: Right.

Sie: Yeah. Those EPROMs are very good devices. It's a semiconductor, compatible with [all semiconductor] processes, right?

Katz: Right.

Sie: And they're a good device. But I mean, they are good for 10 years, the non-volatility is 10 years.

Katz: Well, they guarantee it for that but it actually runs much longer than that.

Sie: Yeah, but it doesn't [scale well] as they start to shrink the device down. The EPROM device is basically based on holding the electrons [trapped] in a dielectric…

Katz: That's correct. It's trapped the charge.

Sie: …to trap the charge in one and zeros, right? But when you start to shrink that thing to a very small area, you know, to maybe 300, 400 microns or something like that, you know, you make [such] a very small device [with correspondingly small and thin dielectric oxide] that the charge starts to leak out.

Katz: So the scaling stops being effective…

Sie: Stops.

Katz: …and you can't get it much smaller.

Sie: That's right, yeah; that's the right word, scaling. Now, they turn to amorphous because the amorphous transition [areas] can be made very small.

Katz: Much smaller than the space that it takes to store a charge…

Sie: To store a charge.

Katz: …in a traditional flash or EPROM.

Sie: And this amorphous [switching] is a permanent transition either in the glass state or in the crystalline state.

Katz: Yes.

Sie: And you could store there forever, [with no limit to the data retention time].

Katz: Right.

Sie: Here's an example: you see these geodes flying from space; these are millions of years old. The outside is amorphous; inside is crystalline, right? You see the geodes with empty centers?

Katz: Yeah, right.

Sie: Right. This stuff came to Earth millions of years ago but they still stored [their original states,] like the inner is crystalline; the outer side is amorphous. And now that means it's truly non-volatile, maybe lasts a million years, who knows.

Katz: But still reversible.

Sie: Still reverse…

Katz: So that means you can use it over and over again…

Sie: Yes.

Katz: …to store— does it take a long time to store or to unstore?

Sie: No.

Katz: About the same as a regular EPROM or flash or E square memory?

Sie: Yes…

I saw recently this Samsung announcement; even using lower power Samsung announced a phase-change memory, 8 gigabytes. They claim that it uses no more than an EPROM. But you asked a question, a very interesting question, is that why it took so long, right, to get this [phase-change] device into the market? The answer is besides scaling factors, because the semiconductor industry is so standardized, so well-established, to support this Moore's Law, so that every second year they double [silicon density and performance], right?

Katz: Right.

Sie: That means their equipment is very well-defined for silicon. If you're adding any other element like tellurium, any of these [amorphous-crystalline capable] elements, you have to change the whole process. I heard, at Intel they worked a long time working with these materials, with the chalcogenide, just to work out how do you put tellurium into your regular process? That's a big subject. Now I think some of the stuff they're working on, because they see the potential, they're setting up manufacturing that maybe is different than the regular semiconductors.

Katz: So what you're saying is that because the regular EPROM or flash technology used exactly the same materials and the same processes as the rest of the semiconductor industry, it was economical and easy to keep building that instead of . . ..

Sie: It's right there, you know, but now if you're going to put in chalcogenide the process engineers say you're crazy, you're putting impurities in there <*laughs*>?

Katz: But that's the only way you can get to scaling to smaller dimensions.

Sie: But that's a trade off.

Katz: Yeah, so alright that answered the question fairly well. So now that you had got some experience in your career with the chalcogenide, and you had worked for a while with Energy Conversion Devices, where they spent a lot of time doing that, what was your next move?

Sie: What happened is that was in 1974. Stan was very good at sustaining that [company], you know, he raised a lot of money, he dedicated himself, dedicated the company to chalcogenide memory. But I think the technical world was not ready for him and the company at that time was sort of contracting. I left and got a job at Burroughs in Plymouth, Michigan, to do component engineering work. In those days, in the mid-'70s you know there was a boom for mini computers and Burroughs was in the middle of it. I became a component engineer and manager to qualify, you know, the 4K DRAM, Static RAMs, all those components used in mini computers. That was my first management job; I had a group [of] about 10 people to do this.

Katz: I'd like to back up just a bit. You started to describe your move toward Burroughs Corporation, having worked for Stan Ovshinsky for a while. Can you elaborate a little bit more on your time with Ovshinsky?

Sie: Yeah; with Ovshinsky I was working on basically trying to commercialize a chalcogenide memory, and to work on the failure modes of the memory, failure analysis. I also worked on organometallic film that used tellurium. Tellurium as a molecule is attached to a photosensitive organic material, so if you expose it [to light], the metal part, the tellurium releases and crystallizes and forms an image; that was work for the US Air Force, and it was very interesting work., But that work relates to something else, maybe that's a side story. [At] ECD, we did not have [a] scanning electron microscope, [or] any of these [large] equipments that [we] needed to do the material work. So we used to rent— we used to go to universities to rent their equipment for material characterization. In those days, Professor Bienenstock from Stanford was a consultant for us, so I went to his lab.

Professor Bienenstock was a material guy at Stanford. So I went to see him, I said I want to look at some surface [views] of chalcogenide material. But I don't want to ruin your equipment; I know some rudimentary operations but you better get your own guy to operate your equipment. He said, "Okay; no problem. I'll get my graduate student to do it." So he sent over his graduate student.

Katz: Who was that?

Sie: Many years ago, he was Craig Barrett <*laughs*>.

Katz: Craig Barrett, the eventual CEO of Intel. We knew that he was originally a material scientist.

Sie: He also learned [well]…he actually did a lot of failure analysis, right? At Intel?

Katz: Right.

Sie: One day I met him at a flight, many, many years later, from Tokyo to Beijing, I bumped into him and he still remembered that experience <*laughs*>. I thought that was an interesting sidebar.

But also there's something else: Stan was very civic minded person; I still remember in those days, we had these anti-Vietnam War marches and he used to let us off a whole day, just go to march in Pontiac against the war <*laughs*>. So he actually had influence on me in setting my political compass. Before that I was sort of apolitical; you know what I'm saying?

Another thing about Stan [that] is interesting is that after I worked for Burroughs for a while I heard there was a job opening at Xerox. I wanted to go from Detroit to California; I always had the wished to work in California, right? So I applied for the job in California, in El Segundo. They need a reference, right? I had Professor Pohm, some other people, and I also had Stan Ovshinsky, because we were still very good friends. Later on in my record at Xerox I saw his response to the inquiry [about me] from Xerox. Xerox asked him, t[hey] said, you know this guy, Charlie Sie? And of course Stan said all the [usual] good things about me, right; he's a hard worker, all this stuff. At the end of this inquiry, the Xerox person said, what do you have to worry about him? Then Stan's answer was so interesting; he said, oh yes, he said, once he joins you guys, the bureaucrats at Xerox [should] start to get worried. I thought that was probably one of the important factors for me to get into Xerox. In those [early] days, [at] Xerox, I tried under Dave Kearns, to start to shake up the place internally, quality and all that kind of thing.

Katz: I'd like to back you up again for just a moment. You described that you would like to get to Xerox after your time at Burroughs in Detroit, partly because of the better geography in California, but I want to make sure we cover what you worked on in Burroughs, in Detroit. Were there any major accomplishments that you want to make sure we hear about?

Sie: Okay one of the issues [I worked on] in those days, I have a small group of five, six people.

Katz: This was in component engineering?

Sie: In component engineering. Even though I was the manager, t I always [was] interested in the detail of the work. We had a soft failure [issue] in these DRAMs. Now it's very difficult to see these kind of failures, because it doesn't fail very often. What happened is in London, UK, we had a bank [customer] there with a large concentration of our mini computers, maybe 30 or 40 of them. And they used DRAMs in them, these mini computers. What happened is every two or three days, one of those DRAM will fail, right? But the interesting thing was after it failed, it recovered; it got very annoying.

Katz: Yes.

Sie: In those days, you know, everybody only knew about alpha particles.

Katz: That was one of the major causes of soft errors.

Sie: Causes of soft errors. Then what we did, we screened those DRAMs, [and found] they have no problem with alpha particles, so it must have been something else. So I started to work on the assumption that it could be the processing of the DRAM., the DRAM has a refresh time, right? It's about a few microseconds; I don't remember the exact [amount of time]; 10 microseconds or so, right? Every cell has the charge stored on the capacitor, right?

Katz: Right.

Sie: And the refresh time really says how long this charge could be held on the capacitor [before needing to be recharged].

Katz: Yes.

Sie: That's the refresh time, right? If we stretch out the refresh time, you will see the distribution of these capacitors. Really what I did in those days, [with] 4K DRAMs, I characterized using an algorithm that somebody [had] written up to test the refresh time, the ultimate refresh time, the capacitor holding time of each one of those capacitors.

Katz: So you could correlate the refresh time versus the usefulness of the capacitor?

Sie: Right; what happened is this. There are 4,000 capacitors there, right?

Katz: Yes.

Sie: You say [for] the refresh, your spec is 10 microsecond, but I wanted to go out to 20 microseconds; I wanted to scan out, [to] see how they fail?

Katz: Eventually one will fail.

Sie: Then I found something very interesting; [in a] really a good DRAM, all those capacitors are very uniform; say your spec is 10 microsecond, right? They [would] all fail around 20 microseconds, so there is a margin of 10 microseconds. Then I further found out that [a] soft failure bit occurs when you do this distribution analysis, [and discover that] there's one bad guy in some chips.

Katz: Uh-huh.

Sie: You see what I mean? The distribution; everything is normal.

Katz: Does that point to a material failure or...?

Sie: It's a manufacturing process [problem]... now if you take a chip, you see one bit stand out, but that bit still is within the spec of 10 microsecond; do you see what I mean? Maybe it's 15, but you… if you statistically plot out, this is the unusual one; that does not belong to the group.

Katz: Right.

Sie: Okay; then what I did was I looked at that particular bit under microscope and I always found the soft failure when there was some defect in the photolithography; very close to that bit.

Katz: Mm-hm.

Sie: So what we did is we went back to the DRAM supplier to show them this process defect, and tell them they have to tighten up their process parameters. And in fact, that solved a class of failure problems.

Katz: Wow that's a very valuable contribution from the semiconductor company's customer into their process.

Sie: That's right. And I in fact, even published a paper in that area and...

Katz: Which companies did you work with on that? Was it... Intel or Fairchild, or Texas Instruments or Mostek?

Sie: Mostek, Intel, AMI...

Katz: So all the DRAM makers?

Sie: Yeah DRAM makers had that kind of soft failures. But they didn't publicize it too much.,

Katz: I know they were all working on soft failures, but a lot of them came from the alpha particles that were introduced during the manufacturing process.

Sie: This was not alpha particles. But the important thing also is [that] after I solved the problem, I published a paper in the IEEE Reliability Section.

Katz: Mm-hm.

Sie: Then that coincided with Xerox recruiting somebody [at that time] to fix their electronic reliability problem <*laughs*>.

Katz: Ah, they got your name!

Sie: They saw this guy, hey he could solve a semiconductor reliability problem. So they started to recruit me. And later on, I found out this very interesting [fact:] I, many years later I found out, they not only recruited me, they also interviewed my boss at Burroughs. *<laughs>*

Katz: Did that guy or woman go as well?

Sie: No, for some reason, the guy who hired me at Xerox, Henry Samuelson, he had been a VP at TRW and he seemed to have an emphasis on candidates' economic backgrounds. I think one of the reasons maybe, I'm guessing, he passed away already, he took me over my [Burroughs] boss was the only difference I could see, I had an advanced degree; I had a PhD and my boss didn't. But anyway, that's interesting side light; that's how I got to Xerox.

Katz: So Xerox brought you in to do your same magic to find flaws in semiconductors that affected reliability.

Sie: That's right.

Katz: Presumably they must have been having similar problems that the computer guys did.

Sie: Right, right, right, but again, it was a soft failure problem.

Katz: Uh-huh.

Sie: The interesting thing is [that it was] always those intermittent failures that were tough, right? That's why you could screen them all the time, [and not find them]. Then they give me [a new assignment], they said, "Charlie, you come establish a company engineering lab. We want you to improve our field reliability." You know in those days, in the late '70s, or mid '70s, they started to make desktop copiers; those small ones, not the 914 big one. And again, they had very frequent intermittent failures in the field. They wanted somebody to fix this problem. In those days, they were really willing to invest [in] a component laboratory to solve this problem because it was a huge field problem, because they were competing with the Japanese. So they hired me and I organized a lab to do the work. And again, people were a little bit surprised, you know, why'd they hire a guy with this kind of scientific background to do engineering work, right? But I said that I always tried to do failure analysis by understanding the device physics aspect. I think that is very important because only if you do that, can you solve the fundamental problem. Then I found it very interesting; at Xerox, in those days we had these PWBAs [(Printed Wire Board Assemblies)], right? One PWBA would be for each copier [model], the desktop copier.

And again, I found I could solve 90 percent of the field problems just by looking at two components. In retrospect, now; one was the optocoupler.

Katz: Mm-hm.

Sie: You couple the electrical signal to your mechanical device through [an] optocoupler because that provides isolation, right? In those days, we were buying optocouplers from HP. I found out the wire inside the optocoupler was intermittent. We took apart an optocoupler, to see what happens. In an optocoupler you have an optical sensor and you have a light emitter, and because you have to sense the light, inside the optocoupler, this transmitter and receiver are packaged in transparent plastic. But the rest of the device is packaged in black plastic, except for the small area, where you need a transparent plastic. Now what I found, was that [the] transparent plastic had a higher thermal expansion coefficient than the regular [black] package material. You see what I'm saying. We couldn't figure out why some of the devices failed more often than the others. But we knew there was a thermal expansion coefficient problem. HP told us the spec on pulling the [sensor] wire strand [was] supposed to be... something around 5 grams. So actually we [were] sort of at a dead end saying "Why are some of them good and some of them are no good? I actually asked HP, "Where did you assemble the device?" And they told me, it is assembled in Singapore. So I took a trip to Singapore to their optocoupler factory so I could see them, right; these bonding machines, right; bonding the optocoupler wire to the [sensor] diode. And now I ask them, how do you do your bonding to [achieve] 5 grams, that's a high bond strength.. Oh they said, we have to heat it up to certain temperature during bonding to achieve the high strength of attachment. Then I said, how do you heat it up? They showed me, they had a rail that long, right? <holds hands about 18 inches apart> They took the device, maybe 20 devices, they put [them] on the rail, and then heated it up, right? They heated up the rail; boom, boom, boom, boom, boom, right?

Katz: Okay.

Sie: To heat it up to do the wire bonding. Then I noticed, I said when you load it up, you finish with one rail, [and] the second rail comes; how do you know you get [the rail] up to that temperature? He said, oh we know it gets to that temperature. Then I tried to observe the temperature. It took a little while, a few minutes for that whole rail to get to that temperature. You see what I'm saying. Then I found out further when they started to load the rail, those [devices which] went at the end of the rail have reached the temperature; those [which] were at the beginning of the rail depending on where they were put on those rails, were at much lower temperature. So we did a pull test [on these]; and we found out, those devices at the front of the rail had a lower [bond] pull strength than those one in the back. So...

Katz: So if they're expanding at a different rate, then it tugs on the wire and it pulls it apart.

Sie: Right, right so then HP was very grateful to us, that we found this problem because it was not only to us; they were selling the device to a lot of other people.

Katz: I expect Xerox customers were very grateful as well.

Sie: Yeah, yeah. So what we did is we defined, when they finished with the rail, the first rail, [and replace it with a] second rail, they would have to wait until the [new] rail gets to the equilibrium temperature before they could start the wire bonding. It was, five to ten minutes; no big deal once you know it, you know? This is one problem we solved that impacted the field results. That's what I meant by doing failure analysis reliability problem from the device physics point of view instead of just by testing. Right?

Katz: Right.

Sie: In testing [and screening alone we could] never get it there. Then the second big problem was a triad problem, you know a triad? Like it's a diode with another lead attached. When you activate that lead, the current flows. It's like a switch.

Katz: Like a transistor, or a switch, right?

Sie: Right, but it's a power device. Again, this one had to do with testing. One of the junctions [wasn't being tested during the manufacturing process. So we defined the device; we changed the test spec and solved the problem. Those two are the major problems.

Katz: Over what period of time were those problems solved? Was this a week, a month, a year?

Sie: Mmm... it's about few months.

Katz: Each one?

Sie: Once you get onto it. But it takes long time to... to analyze it. Once you find a problem, within six months, we solved the problem, the complete problem for the identification...

Katz: And a solution.

Sie: Solution. .

Katz: Okay so you were at Xerox a long time though, you must have had other problems or other work assignments than just finding component problems.

Sie: At that time Dave Kearns was the CEO of Xerox. He was really trying to improve the quality of the copiers and printers because we were competing with the Japanese, after the decree that we had to open up our patents for the Japanese. In those days, I was working in El Segundo, you know Aviation Boulevard, and we were making one million [printed circuit] boards a year, that's quite a few boards. I fixed problems for these one million boards <*laughs*>, you know, and...

Katz: Must have been quite a hero?

Sie: Yeah, yeah, yeah. They thought Charlie could do that, right? So they asked me to later on to manage the board design activity.

Katz: I see.

Sie: Then also they asked me eventually later on to manage the firmware [development] process. At Xerox, these boards ran on firmware. I told my management, "I'm always interested in new challenges, so don't put me on the same thing for too long." <*laughs*>

Katz: Aren't we all.

Sie: In those days, early '80s I introduced Japanese components into Xerox products. You know at that time, people were worried, about using Japanese components in the early '80s. You know, they—

Katz: The early '80s was about the time the Japanese were demonstrating they could make pretty good components.

Sie: Right, right; but we didn't believe them. <*laughs*> I made many trips to Japan because [their components were] much lower cost. I still remember the component supplier I dealt [with] most was Toshiba. We established a very good relationship in this exchange. And we established very good reliability on our copiers and printers and other things.

Later on I was trying to establish hardware and firmware platforms for Xerox because we made, say 30 and 40 different versions of the printers and copiers, right? A lot of products there and for every one of those, you started a product development always from ground zero on electronics. That's not right, right? So I even went to Rochester for five years to work because that was closer to the printer and copier factory. I helped them to initially establish [a] hardware platform for controllers for all the products, so when you start a product, you don't start from ground zero. You start from this set of hardware right?

Katz: Basic hardware and mechanics. Then personalize it with the firmware.

Sie: Right, and we designed— we actually started with a common chip; we had a custom chip and for [each] different [end] product, we just put in different firmware.

Katz: Who made the chip for you?

Sie: The chip in those days I think— I'm not too sure now. Toshiba was one of them, but I don't remember— there were other people who were making [custom chips]; I have to go back and look, but Toshiba stands out in my mind.

Katz: They were very competent ASIC suppliers; custom chip supplier?

Sie: That's right. Then besides this [chip], we established a hardware platform. Then we started to establish a firmware platform, so you would have a set of [standard] firmware you could use to really, emphasize time to market. In those days, I did not know too much about [firmware]... I was electronic guy, right? But there was a guy at Xerox [who] influenced me a lot.

Katz: Who was that?

Sie: That name is Maurice Holmes.

Katz: Hmm.

Sie: He was one of the smartest engineers I ever met. He showed me what to do, what I would have to do in turn, on order to make this platform [which] could be common to many [end products.]— He was a mechanical guy, and he actually was my boss at that time. He looked from the mechanical aspect, from the system aspect. I worked with him very closely. Then afterward, they could see [that] I could do these things, right? So they established a corporate engineering center; one in Rochester, one in El Segundo. And they appointed me [to be] the Vice President of the Corporate Engineering Center on the west coast.

Katz: That was predominantly for printers and copiers?

Sie: Yeah, yeah.

Katz: What involvement, if any, did you have in the computers that were done at PARC (Palo Alto Research Center) or also at El Segundo?

Sie: This is another story <*laughs*>. We [had] established a process for basically how to productize technology, right?

Katz: Uh-huh.

Sie: So in my last year at Xerox, they asked me to go to PARC. I said, what do you want me to do at PARC?

Katz: What year was that?

Sie: That was 1998.

Katz: Okay.

Sie: He said, Charlie, we want you to go down there to show them how to productize some of their concepts.

Katz: PARC had a lot of good ideas but they didn't manufacture anything, did they?

Sie: Then I learned that in productizing hardware and productizing software, they are two different animals.

Katz: Mm-hm.

Sie: The software is more flexible, more— even though it's not visible, but... you could visualize it and implement it quickly.

Katz: Mm-hm.

Sie: With hardware it's difficult. You could visualize it but you could not prove it very quickly; it takes time; it takes prototyping, [design for] manufacturability. But with software it's much different.

Katz: But you still have to do all the testing on software.

Sie: Yeah that's right.

Katz: All the conditions are going to be met.

Sie: My contribution to software development in Xerox was how to... you see, one tricky question in software [development] is did anyone ever ask you, when do you stop testing software? *<laughs>* You could go on testing software forever, right? *<laughs>* Again, I learned something from this experience]... you see I was a chief engineer for a Xerox color printer called the 4700. It had a lot of software testing. Maurice Holmes, my boss, asked me, he said, Charlie, you're chief engineer of this product? I said, yeah. He said, Charlie, when do we stop testing? *<laughs>* I didn't have an answer, you know? So I did some research. Then I found out that people in the University of Hiroshima, there was a professor [who] wrote some wonderful papers on how to [decide when to] stop testing software. There is this so called Duane curve. If you plot log-log everything's a straight line., And what you could do in testing software, you could plot [software bug incidents]on the Duane curve like you keep accumulating... when you stop testing software it generates errors, right? And you could see the errors come up, right? Then it saturates, then it asymptotically reaches some value [as the frequency of finding new bugs declines]. You see what I'm saying?

Katz: You reduce the frequency of bugs.

Sie: Bugs. But there's an inflection point right in the middle when this thing goes up, then it starts to come down, you know, the inflection of the slope. And by looking at the inflection point, you could actually predict what is your ultimate asymptotic value and how long you have to do the testing.

Katz: Hmm. Interesting.

So Xerox started using that technique?

Sie: At least in my products. But sometimes [it was] hard to explain to other people, using this testing methodology. Then one year, after I retired, there was some Indian consulting company [that] invited me to talk on that particular project in China…I got a lot of resonance from the software testers in China. I think those are important parameters in software testing, for products because like you know, you could test forever, right?

Katz: Indeed.

It looks like we've covered most of the arc of your professional career until your retirement. Anything you want to say about your life after retirement?

Sie: After my retirement, they're two separate areas I get involved [in]. One still is the technical area; the other one is more civic minded.

Katz: Okay. Tell us about each, please.

Sie: in the technical area I'm still involved with [the question of] how do you implement software in ERPs especially.

Katz: ERP is enterprise resource planning?

Sie: Planning, right; But how do you implement a particular piece of software, that software system into your enterprise?

Katz: Mm-hm.

Sie: That piece is lacking. What [typically] happened is, you know, based on statistics say 85 percent of the software, ERP implementations either are over cost, or over schedule, or you implement it, [and then find out] nobody's using it in your company.

Katz: Hmm.

Sie: And what we tried to do is to see from the Xerox experience, [if we could] come up with a model of how do you implement software. And it is rather simple. That particular mindset is really you look at implementation of software as the matching of two cultures. You see what I'm saying? We look at a company; you're working at a company; the company has it's own culture, it's own work processes; it's habits. Then on the other side is the software. The software has a set of algorithms. They have these processes, too.

Katz: So it behaves on it's own..

Sie: Yeah, it behave [according to] it's own culture. So the whole idea— I mean it's very simple idea: How do you merge those cultures in a rational way? You either change your working culture, or you change the software culture, you have a choice., But you [must] do that before you implement your software, so you do everything with eyes wide open, whether you [intend to] change your enterprise working culture, or change the software, then you start to implement it. Then you will have an effective way of implementing software.

Katz: Do you do that work on a consulting basis?

Sie: Yeah; consulting basis. And what we did is we took the Xerox model and implemented an ERP. Of course Xerox is a big company, right? They have 50 locations; [so] it's a big ERP. It was an Oracle ERP [system.] We used the Xerox experience to establish a model, and using that model we implemented an ERP at a biotech company in San Diego; this [company] was only 20 people. And we use exactly this concept of matching of two cultures. We did it in 47 days, even though— of course it's a very small company and couldn't afford Oracle; we used the Microsoft Great Plains. That's a much smaller package. And for the manufacturing package, we used the Horizon package. We integrated that for a small company [for use] in the manufacturing [of] biochips, bioslides. And it works to this day.

Katz: So that's some of your retirement activity.

Sie: Yeah.

Katz: I think I'd like to explore your civic activity but we're running a little low on time now and I'd like to do that as a separate conversation at a later date, maybe?

Sie: No problem.

Katz: Okay I'd like to close up the discussion here with some words you may have for young people who may want to follow a similar career path to yours; that is become very technically competent and apply that competence to various business enterprises. Can you offer some advice for young people?

Sie: I think [a good plan] for the young people is... don't be afraid doing something new, right?

Katz: Even 40 years ahead of it's time.

Sie: <*laughs*> No, [as] I look back, I was crazy; making those films but I thought that was important, you know, whenever you're doing something, you think that's the most important thing in the world, you know. When I was making those chalcogenide film, 35, 40 years ago, I thought that's the big thing; that's something [that's] going to change the world. Even though we've been through 30, 40 years, and nothing happened [with phase change memory.] But it [finally] came out, right? Like also when I was doing the soft failure [analyses], all those things. When you do something, you always think, that's the most important thing in the world.

Katz: Okay?

Sie: You see what I'm saying. Now the other thing I think is important, is record down what you have done; write it down; write a paper, you know, write a note. Like this video I made in 1969 on the filament growth, right? It was recorded on 16 millimeter film. If I didn't have that film, all this knowledge would have gone to waste.

Katz: Right.

Sie: And recently, I looked into this. When you publish something, about some work you did, sometimes [it's] very hard to say how did it impact the world. It's very hard to say. Then somebody recently showed me, how to look at what I have published in certain areas, the Google citation index. I never knew. I thought this 30, 40 years in between, nobody looked at my stuff. Then I found out, my work on this filament growth was cited 250 times. I looked on the Google [citation index, and found], there's 250 times, about 90 percent [of which] was cited by other people applying for patents.

Katz: Hmm.

Sie: So that's very interesting; you know, from Micron, from Intel, from all these companies. That means my early [work]— I didn't apply for a patent but at least it made [an impact]...

Katz: But you did publish something.

Sie: Published something that it made a difference in the world. So I think it's important for the young people to write down what you have done, you know, even though in informal notes or something.

Katz: Never know when you'll need it.

Sie: I mean I think, your life... goes through very quickly. So don't afraid of doing different things. You know, in my life, I went from chalcogenide to reliability, to <*laughs*> software, firmware, then to software implementation, ERP, I think these are all challenging things in life. We technically train people have those kind of opportunities.

Katz: Right.

Well thank you very much for the time you've spent with us today and as I said, I hope we can get together again and look into your civic activities because they sound interesting as well.

Katz: With that, I think we'll close the conversation.

Sie: Okay.

END OF INTERVIEW

