Oral History of George Perlegos

Interviewed by:
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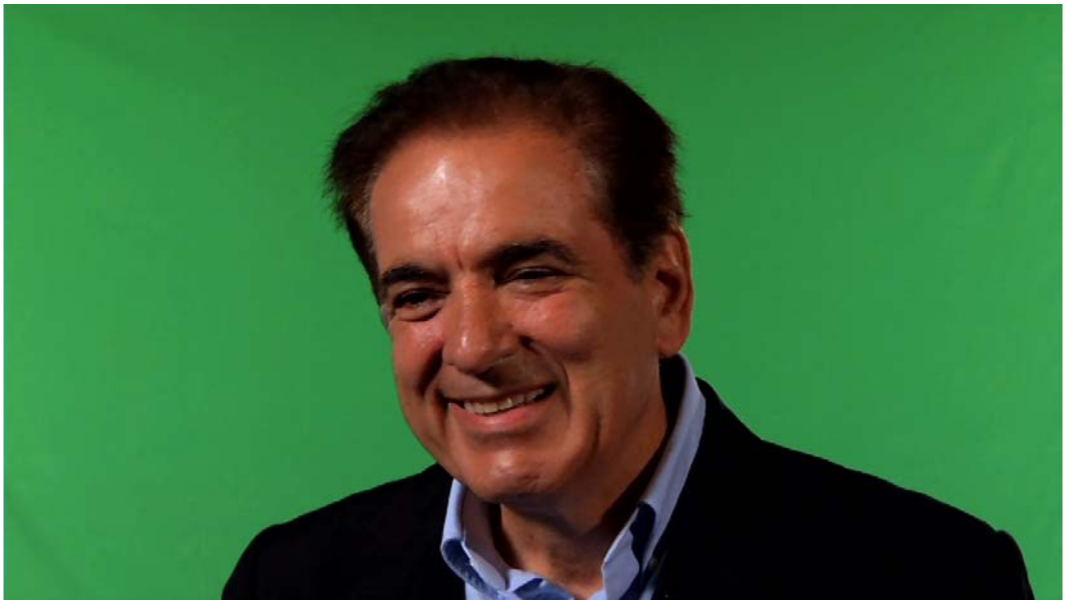


George Perlegos, July 8, 2013

Jeff Katz: We'll begin now. We are in the Computer History Museum on July 8th, 2013. We're visiting with George Perlegos, who is one of the seminal people in nonvolatile memory design and development. He went on from early technical success at AMI and Intel to co-found and manage several successful semiconductor companies, including SEEQ Technologies, Chips and Technology, and Atmel. I'm Jeff Katz, the interviewer, and a former long-time employee of George at Atmel.

We shall begin with a question that's easy for George. Can you describe your early life and education? Where did you grow up? Where did you go to school? What did you study?

George Perlegos: Okay. I came to US from Greece in 1962 and I finished high school in Lodi, California and then I went to San Jose State University, where I got my Bachelors in Electrical Engineering in 1972. After that I attended Stanford University from 1972 to 1978 where I received my MSEE and continued my graduate studies.

Katz: What kind of family were you in?

Perlegos: Well, my parents were farmers.

Katz: In Greece as well as in California?

Perlegos: In Greece as well as California. My father is here for many, many years now is a wine maker. He's got grape farms and he's still doing that now. He's 92 years old. So, after San Jose State, where I got my Bachelor's, I went to Stanford University and I got my Master's in '75, and then I continued graduate school at Stanford University. I stopped in 1978 because I was too busy. At the time, I was working for Intel.

Katz: Well, I have an earlier question there. What made the son of a farmer decide to become technical? What influenced you in that direction?

Perlegos: Well, my mother always wanted me to go to school, so that was one. I had somebody pushing me to go to school. We are three brothers, and all three of us went to the university, and I think we have to thank our mother for that.

Katz: Well, it's clear that your parents influencing you to go to school is an important thing, but I'm still curious about how you ended up in technology instead of in agriculture.

Perlegos: Well, I started in San Jose State University to become a doctor, medical doctor. But when I came to San Jose State, a lot of engineering was getting developed at that time here [in the Valley]. I was diverted into engineering, by accident or whatever.

Katz: Was there a particular person who influenced you?

Perlegos: I don't remember. I think— my brother, Gust, was already in electrical engineering, and I switched to be in the same field. It was a new field, interesting—

Katz: Oh, I know that feeling well. I did the same thing about five years before you did.

Perlegos: So, I followed his footsteps.

Katz: Very good. Well, electrical versus other engineering, I guess that was another following a big brother; because he thought it was a good idea you might have, as well. When you got out of school, you said you had worked for Intel, but tell us about the first job you took out of school.

Perlegos: Okay. When I finished San Jose State University, I started working for American Microsystems. I got my first job before I went to Stanford University and before I went to Intel. My first design assignment was to design a single-chip calculator. And I was asked to design—

Katz: What year was that?

Perlegos: In MOS, in 1972.

Katz: So, that was about the same time Intel was already working on single-chip calculators, but they ended up calling them microprocessors.

Perlegos: Yes, I didn't know too much about the MOS devices because I had studied bipolar. When I finished the university, right away, I went to Stanford University at the same year. I knew exactly what classes to take, what to study, because I was working in an area which was telling me, you got to learn these things. I learned about the MOS devices, I learned about MOS processing, circuits—my path was set, just because of my job requirements.

Katz: How long were you at AMI?

Perlegos: I was at AMI about a year and a half. At the beginning of '74 I started with Intel Corporation.

Katz: At AMI, who were your big teachers who taught you all of this MOS stuff?

Perlegos: Well, there were many. There were many people there at that time. There was Phil Siu, Danny Tjoa, some of them worked for Intel, Imo Jung. AMI at that time was also one of the pioneering companies in MOS.

Katz: Well, they were not only doing calculators. They were making memories too, weren't they?

Perlegos: Memories, custom designs. They were doing many things at that time.

Katz: I remember that, because I was trying to buy memories from anybody who made them, and they were on my list. Well, what made you decide to leave AMI, and under what circumstances was that?

Perlegos: Well, I was now going to Stanford for two years, and I came for an interview at Intel. They had a new project to develop, nonvolatile memories, or to develop a new chip. I didn't know anything about it, but it sounded interesting, so I left AMI and I came to Intel.

Katz: Okay, that was a typical move in those days. You had to move around to learn more things from different companies and different teachers. Who were your first teachers at Intel?

Perlegos: Well, right away, I got to work with Phil Salisbury, Dov Frohman. I got to work with everybody, so I met Gordon Moore, [Bob] Noyce, Andy Grove, and many more.

Katz: What size was the nonvolatile memory group at that time?

Perlegos: No, it was nothing. It was very small, only a few people.

Katz: So, you got exposed to the whole—

Perlegos: Yes, I became like the device guy, circuit guy, process guy, because I had the knowledge from Stanford, and I was able to step in and help out the others complete the development.

Katz: Interesting. What were the first products that came out of that effort?

Perlegos: At that time, Intel had a P-channel EPROM [erasable programmable read-only memory], which was developed by Dov Frohman, the 1702, I think. So, our objective was to develop an N-channel that was able to work with the microprocessors that Intel was developing at the time. The first project that we defined was the 2708.

Katz: Let's help the listeners here for a moment. What's the difference between P-channel and N-channel from the standpoint of being able to work with the microcontroller?

Perlegos: Well, one thing, you can think about it, one has positive voltages and the other one has negative voltages. At the memory device, what we were trying to do was to make it work with only positive voltages, so the N-channel. With the P-channel, we had to use negative voltage, and that was more difficult, and the voltages were much higher.

Katz: And those higher voltages didn't exist, probably, with the microprocessor..

Perlegos: That's right. The microprocessor technology had moved from P-channel to N-channel at that time, so they had to develop new technologies to do that. And they had to develop memory. The idea was to develop a memory that retains its charge, so when you take out the power, if you program 1 and 0 into this memory, it retains, unlike the DRAMs or unlike the SRAMs, where when you take out the power, it loses its memory content. This was the first time after the 1702, to develop a high-density memory, to be able to retain the programs that were written for the microprocessor. So, it was a very big invention; it helped out the development of microprocessors tremendously.

Katz: Did it emerge at the same time that the microprocessors did?

Perlegos: Same time, yes . . .

Katz: So, I presume, then, you had to coordinate with the development of those chips.

Perlegos: We had to coordinate it in terms of the voltages and in terms of the signals. They [the microprocessor folks] were giving us the signals the microprocessor would give us and how they wanted us to make the memory work.

Katz: Was that memory organized by byte or by bit or by word or what?

Perlegos: By bytes, so it was to work with, I believe, the 8080 microprocessor that Intel developed at that time. A microprocessor at the time, 8-bit wide. So, we had to develop a matching memory, and normally that was 8-bits wide.

Katz: Interesting. Okay, so, that came out, and I presume it was a pretty good success, because I recall that when I was working on microprocessors, it was costing the company money, but Intel were getting paid for that investment by the profits from the EPROMs.

Perlegos: That's right. It [the 2708 NMOS EPROM] was one of the revolutionary chips. Intel had it and nobody else had it, and it was a big success. It helped the microprocessors tremendously to be able to write programs, do the BIOS [for PCs] on the EPROM and be able to start up the microprocessor [business] at the same time. So, it was a big success. So, slowly, revenues ramped up. Everybody started buying them to be able to develop their microprocessor software.

Katz: Were there any particular problems you had to solve to get those things to work when no one else could?

Perlegos: Many problems. Developing nonvolatile memories were brand-new at that time, and especially the N-channel. So, we had to develop many things. We developed a memory that was with two layers of poly, one layer of poly on top of the other. That was one big, big problem. We developed the Channel Injection Technology. We had to develop circuits that would handle the high voltages. In order to program the EPROMs, we required like 10, 20 volts. So, we had to develop high-voltage transistors. Then, we had to—

Katz: That means what? A high-voltage transistor has thicker materials?

Perlegos: Much thicker oxides and different junctions so that it will not break down, and it goes to 20 volts. Then we had to develop everything that is needed to make these kinds of memories reliable. They had to retain a charge for 10, 20 years. So, we had to test it and prove that it can retain that.

Katz: How did you do that in only a year if you had to wait 20 years to find out if it worked?

Perlegos: Dov Frohman helped us develop testing techniques such that if we bake the devices at much higher temperatures, it accelerates the aging. We had two problems with what we call DC erase. That means when we tried to program 1 bit, another bit got erased. So, there were many problems we had to solve. But fortunately, good for us, we had the knowledge of how the devices worked and we were able to fix all those problems; fix them either with circuits or with process, and make it work. So, we were very successful. And the program went very fast.

Katz: Over what period of time did all that problem-solving occur, and with how many people?

Perlegos: We had about two, three people. I was the only designer and device guy. We had a process guy, Dick Simco, who I think was doing the processing. Bill Morgan was also in processing. Phil Salisbury was the manager. But Dov Frohman was the consultant. He had gone to Israel at that time, but he was always helping out. So, it was an important project.

Katz: And when that project ended and it began to go into production successfully, what did you work on next?

Perlegos: We continued. Intel continued developing new microprocessors. They developed the, I believe, the 8085 or whatever, which was 5-volt microprocessor. So, we had to develop a memory that would work in only 5 volts. I developed the 2716, a memory that would work with only one external voltage, 5 volts. 2708 had been working with 3 voltages, -5 for substrate bias, and +5 and +12, so it had three voltages. So, now, the 2716 was only working with only one voltage, +5. To take care of the substrate, we used ion implantation, and we made the cells smaller, because we needed bigger memories now. The microprocessors wanted bigger programs. People were writing bigger programs, so we developed the self-aligned polys. We were able to etch one poly on top of the other poly and straight down. That reduced the size of each cell. The big development in here is we also developed the sense amplifier, how to sense the content of these kinds of memories. I believe the sense amps that we developed at that time are still used today in all non-volatile memories, whether it is EPROM, E-Squared [also known as EEPROM], flash memories, everything. I was able to do that very quickly in 2708, because when I was going to Stanford, I had developed a differential amplifier that was used for hearing aids. It was able to detect very low signals. So I used that knowledge to quickly put together a sense amp to sense the 2708 [and later, the 2716] memory content.

Katz: Well, that's interesting. I never knew that there was hearing-aid technology in the memories.

Perlegos: Well, it was the sense amplifiers that we were using. There were many techniques that I developed and are still used today.

Katz: Okay, so, now you're up to 5-volt-only EPROMs, and I presume they still required to be programmed outside the systems.

Perlegos: All the EPROMs that we developed, the 8K and now the 16K, all these memories required that we program them [outside the system]. They retain the charge forever, 10 years, 20 years—

They also had to be UV erased, and that was the big drawback.

Katz: The programming and erasing had to be outside.

Why was that? Why did they need to be programmed outside?

Perlegos: Because of the voltages. In order to program these devices, in addition to the +5 volts, the programmer has to supply 20 volts to be able to program the device, because all these devices used new techniques. The technology that we developed was to generate hot electrons, so we applied 20 volts [by the external programmer] and we were able to generate hot electrons in the channel of the device and those electrons were pulled across the oxide and into the floating gate by the voltage we applied to the top gate of the two layer poly memory cell.

Katz: Okay, so, you were trying to solve two main system problems that existed with the EPROM. One is that they had to have high voltages to program, so it couldn't be done in the system, and two is that they needed to be UV-erased.

Perlegos: UV-erased.

Katz: That's also outside the system.

Perlegos: Yes. The development continued, you know, in both the devices, in the technology, the processing. So now we had to develop a new device that would not require the UV erase. The EPROMs also continued, because memories were getting bigger and bigger. We developed 64K, 256K, because the programs with microcontrollers now also became bigger and bigger. People had been using floppy disks to store the program, and by us using EPROMs, we were able to replace the floppy disks. In the old computers, if you remember, people were using floppy disks. So, the advantage of our devices were to replace all those things—

Katz: Which made the system smaller and made them operate quicker, more reliably, and everything, yeah.

Perlegos: So, the next technology that we developed was what's called the E-squared technology, non-volatile memory now that required no UV light to erase.

Katz: Was there some external motivation, or were you just evolving the technology? Did somebody say, "Hmm, why don't we work on something that doesn't need a programmer or a UV?"

Perlegos: There were people like Jeff Katz from marketing <*laughs*> always coming up saying that, "Hey, you know, we need to be able to alter our programs [in the system, not in an external programmer]. We have our microprocessor, we have our memory, but sometimes we want to be able to alter the program on the system board. So, if we collect some data, we want to store this data [in real time], you know, and retain this data."

Katz: I know I would have said that, but I don't think it was I who did say it. Who was it in marketing for the memories?

Perlegos: Davidow. [In microprocessors.]

Katz: Oh, it could have been Davidow, yeah. But I was only asked to define new microprocessors. I wasn't talking about how the memories worked at that time.

Perlegos: Anyway, there was a requirement for the microcontrollers to take in data and be able to alter its data. That was an incentive now to develop a memory that we could program and erase on-board.

Katz: Were you aware that anyone else was working on that kind of a problem?

Perlegos: There were many people working, trying to create that, but nobody [else] was really successful in developing new [non-volatile] memories at that time.

Katz: I think by the time Intel was up to the 16K or the 32K EPROM, other people had started making EPROMs.

Perlegos: Yes, [some] other people did.

Katz: But nobody was able to make one that was in-system, erasable, or programmable.

Perlegos: Yes. Other people started working on them, but we also started working on it, even though, you know, you might not see it in [the] literature, we started working. In '74, we developed the 2708, '75, we started developing the 2716. About 1976, we started developing the E-squared the 2816. E-squared now took a little bit longer to develop, because when we go to E-squared, we had to solve many more problems than we had with EPROMs. Now our technology devices change completely. Instead of creating hot electrons, we had to use tunneling. We tunneled up to program, and we tunneled down to erase. So, we had to be able to create voltages—

Katz: Can you explain the difference between hot electrons and tunneling for our listeners?

Perlegos: Somebody, I don't remember who, gave me this explanation: It's like standing on top of a bridge and you have water going under the bridge, and you have the water molecules collide with each other, and you get some drips of water over the bridge. Essentially, this is a very good analogy of how hot electrons are generated. You have electrons traveling like water is traveling. They collide with each other, and then some of them go in different directions. Some of them will go up, and those were the ones that we had our voltage on top of it pulling them over. So, it's like pulling them over the bridge, and the bridge is your floating gate poly.

Katz: And that, once they got up there, they got stuck there.

Perlegos: So, the idea is to get them up there and through the oxide, not be trapped in the oxide, because the oxide has many holes or whatever. So, they have to have enough energy to cross the oxide and not be trapped in it—and go into the floating gate poly.

Katz: Okay.

Perlegos: But tunneling, now, works a completely different way. You don't have any hot electrons bouncing into each other or anything. The technology says that if you apply a high enough voltage and you have a thinner oxide; you can attract electrons to cross the barrier. There is some voltage barrier that prevents the electrons from crossing the oxide. So, if you apply a high enough voltage and that's your tunneling voltage, you get the electrons to cross the oxide. Okay?

Katz: And if you apply it the other way? Then they'll jump back down?

Perlegos: Yes. So, this is another advantage. E-squared requires [almost] no current to flow it's done with very low current, no power. So, whereas the EPROM require a lot of power to program it, the—

Katz: Oh, that's, I guess, another reason programming EPROMs couldn't be done in the system, because it would use up too much system power.

Perlegos: Yes. So, anyway, we started developing the E-squared so we can program and erase in the system itself.

Katz: Were you aware of the other competitive efforts to do in-system programming and erase.

Perlegos: Yeah, we were not [officially] aware of that, but we were aware, right? So, we had to use [very thin] 100-angstrom oxide; people had developed the 100-angstrom oxides before. But they did not know how to develop them reliably or clean enough so that when electrons tunnel through them they don't get trapped through it. So, we had to be able to figure out a way to grow these oxides reliably with very few holes inside so electrons don't get trapped there, and—

Katz: What was that way? What did you have to do to get a good oxide?

Perlegos: Okay, I don't remember now. *<laughs>*

Katz: I presume it had to do with purity or something.

Perlegos: Yeah. It had to be grown in a different atmosphere—in different conditions, okay? I have some slides there that explain it, so maybe later on we can go through it.

Katz: Maybe we'll get those out. I may want to ask you later if we could photograph those for our archives.

Perlegos: Well, that was the big development. Over this history, we developed the [EPROM] non-volatile memories with hot electrons, and now we developed new memories, which are, again, non-volatile memories but with tunneling, and that's the E-squared device.

Katz: E-squared never did replace EPROMs completely. Why not?

Perlegos: Well, over time, it did. Over time, it did. It just took a much longer time.

Katz: We ended up calling them Flash when they finally did. But the original E-squared—

Perlegos: It was much more difficult technology, because it was difficult to grow the hundred angstrom [oxide], and that's—and then later, we required even thinner, 80 angstroms or something to be able to utilize the right voltage. In order to program these devices and get them to tunnel, we again required 10, 20 volts, and we had to have a little bit thinner oxides than 100 angstroms over time to make the tunneling voltages even lower, so that they were able to play with the voltages of the different technologies that we were developing at the time.

Katz: System voltages?

Perlegos: System voltages; not only the system voltages, but also on-chip voltages. Remember, we said—

Katz: Okay, please explain the difference there. There was no 20 volts in the system, was there?

Perlegos: No. Initially there had to be. That was the disadvantage.

Katz: Ah.

Perlegos: Initially there was. We had to have 20 volts in the system to be able to program and erase the devices. Then, after—I don't know if you want to go there, after I left Intel in 1981, then I went to SEEQ Technology. There we were able to develop a new technique. I developed a new technique that was able to create these high voltages on-chip. We developed on-chip charge pumps and everything else, all the other circuits, so now we didn't need any [extra] external voltage at all, [only the 5v that the microcontroller used]. The advantage of E-squared was that, as I said before, we required very little current, okay? So, we just needed a high voltage with very little current. So, we were able to then create the charge pumps on-board to do that. Which created 5-volt-only E-squared memory. We were the first to do that.

Katz: Okay, we'll get back to what you did at SEEQ in a minute, but I'm curious about something: you said you left Intel in 1981. What were the circumstances behind that? Why were people leaving Intel at the time, and why were you among them?

Perlegos: It's a long time ago now. <*laughs*> I had stayed at Intel and developed many different devices at Intel. Intel was growing tremendously at that time. They were very successful in the nonvolatile memory, EPROMs, E-squares, very successful in microprocessors . . . I was traveling around a lot. We had to transfer our technologies to the fabrication facilities in Oregon. We also developed fabrication facilities in Arizona. We developed design centers in Sacramento. There was discussions and talks that made me believe I had to leave and go to Sacramento. I did not want to go back there. It was too hot. <*laughs*> So, I guess, the SEEQ opportunity came along, and I left, and that's how it happened.

Katz: Well, it wasn't only you that left. There were others. I mean, there was a whole team that formed SEEQ, and they were mostly Intel people, weren't they?

Perlegos: Mostly Intel, yeah. Mostly Intel people.

Katz: So, it was all people who did not want to move to Sacramento?

Perlegos: I was the engineering guy, VP of Engineering, and there was Gordie Campbell, Phil Salisbury. Like I said before, Intel was growing tremendously. They were forming new divisions. They were moving to new areas, and some people did not want to go through that. That gave everybody an opportunity—you only need a push, and maybe that was the push that pushed some people out.

Katz: Well, there was an earlier departure, wasn't there—the people who formed Xicor? That came before SEEQ?

Perlegos: That came way before SEEQ, yes.

Katz: And they were working on E-squared, as well. Were they part of your original team?

Perlegos: No. They were a different team. They left Intel and they formed Xicor. They were developing E-squared devices, but using a completely different type of technology than either the EPROM technology that we have been discussing or the thin-oxide E-squared technology with tunneling that we talked about before. They were trying to get tunneling through a much thicker oxide. So, they were developing different devices. They had been in a different Intel group. That group was mostly like a CCD group. Intel were so successful in non-volatile memories. They were very successful in microcontrollers.

But not the CCDs, they abandoned that group. So, that group got together and left to form Xicor. I believe that's how it was.

Katz: I have a recollection that Intel sort of supported that departure and helped them, or became an investor or something in Xicor.

Perlegos: Yes, I don't know that. I don't remember that.

Katz: So, that might have been a friendly departure. Was the SEEQ group a friendly departure?

Perlegos: No, absolutely not. Intel did not want to lose me, and that was not a very happy occasion. It was not.

Katz: Yes, I remember an anecdote—this is probably true—that Ed Gelbach was mad at Gordie not for starting SEEQ but for taking George with him.

Perlegos: Yes. Ed Gelbach was somebody that really liked me and supported most of the projects that I did at Intel.

Katz: All right, so Intel eventually succeeded, even without you.

Perlegos: *<laughs>* Of course.

Katz: But SEEQ didn't, after a long time. I guess at the beginning, it was probably fairly successful. Tell us about what happened in the early days of SEEQ.

Perlegos: You can look at it, you know, my development in this Silicon Valley continued, whether I was at Intel or was at SEEQ. My motivation was to develop new devices and new memories and new systems. At SEEQ, my objective was to develop a 5-volt-only [non-volatile] memory, and I did that. We developed the 16K 5-volt-only [E-squared] memory.

Katz: And your role there was . . .

Perlegos: The VP of Engineering, but I was giving the direction. Most of the designs were done by—

Katz: Did you have a big team working on it, or did you do the work?

Perlegos: I did quite a bit of the work. I started out with a small group, but eventually it grew to be big. And we were successful at SEEQ. SEEQ started in 1981 and we developed our own fab, which was difficult. We had to have enough money to do that, develop our own technology, our own circuit. We went public in 1983. So, from 1981 to '83, that was a very quick success at that time. But I left SEEQ in 1984, so it wasn't a long stay at SEEQ.

Katz: What were the circumstances of departing as the VP of Engineering?

Perlegos: As I said before, you know, SEEQ developed a lot of new technologies, and we were successful. We developed a 5-volt-only memory, which was very important at the time. It was working okay. People were buying it, but in order to develop SEEQ, we had to develop our own fabs, so we required a lot of money.

Katz: From where did that money come?

Perlegos: From venture guys. Kleiner Perkins and some other people. Kleiner Perkins was the first to invest at SEEQ and we spent a lot of money. I guess our portion in the company became smaller and smaller as we raised more and more money. So, I think that was one motivation that allowed us to leave.

Katz: Dilution, yes.

Perlegos: Dilution. I think also Gordie Campbell eventually did not have a good relationship with the venture guys, so that also caused him to leave. And then eventually I left too.

Katz: So, the President and the VP of Engineering left, which left SEEQ as an empty shell.

Perlegos: Yes. <*laughs*> Well, they had many other people there. At that time, SEEQ was a much bigger company. We were developing not only memories. We were developing microcontrollers with E-squared on-board. We were using the Z8. We were developing Ethernet controllers. We had migrated to many technologies.

Katz: Interesting. And what size staff did you have at the peak?

Perlegos: Oh, boy, I don't remember now. I don't remember.

Katz: A dozen? A hundred? A thousand?

Perlegos: Not a thousand, not a dozen. No, maybe we had ten, twenty people developing circuits.

Katz: All right, so, with further dilution, you were not likely to get as rich as you thought you might, and the company was pretty well spread out over many technologies—

Perlegos: And it was a public company.

Katz: I suspect not all of SEEQ's technologies were as successful as the early nonvolatile memories.

Perlegos: No.

Katz: Because there was more competition in some of those logic systems.

Perlegos: That's right. Yeah, the one memory that was very successful was the 5-volt-only E-Squared. You can say that we pioneered the 5-volt-only technology, which is used everywhere today in the E-squares, and in the flash memories—

Katz: And that's by putting on the on-chip charge pumps?

Perlegos: By putting charge pumps. We had to put charge pumps on every column and every row. This is a big, big technique**:** We had to develop charge pumps small enough that they could go on every column and in every row in order to develop a memory like that.

Katz: Well, that's a new thing for me. I thought there was a single one for the whole chip.

Perlegos: No, no, no. We had one big charge pump to create the 20 volts that you need to tunnel. Okay, so that was only one in the chip, and then there were little charge pumps to take that voltage and transfer it on to the columns and to the rows, so [it was] a big, big achievement at that time. Now, the other development that I worked on—if we go back to Intel for a minute, you asked me a question, what was the organization of the memory? Microcontrollers from the beginning were working with 8 bits, so we had 8-bit words. So, now we had to develop a memory, E-squared memory that would work with 8 bits. So, in the EPROM, it's very easy. You can line them up, and they would work as 8-bit memories. You separate them. With E-squared, you couldn't do that. So, we had to develop other techniques. [At Intel] I developed a circuit technique or a pattern where I was able to take the 16K E-squared and organize it in 8 X 8 bits—

8-bit words. So, if you look at the first E-squared memory that was developed or all E-squared memories when they are working today, they were organized as 8-bit words, and that was the patent that I developed at Intel, as well as a lot of other things. There were a lot of things that we had to do. It wasn't just that one thing to make this technology evolve. You can think of a technology, you can make a technology, but to understand the technology and put it into practice and make a real memory that works and is reliable, it's another thing. We were very, very successful in Intel to pioneer all these things. So, it's very difficult to describe it by my hands. <*laughs*>

Katz: Well, I presume you got a lot of patents during that process, both at Intel and at SEEQ.

Perlegos: Yeah, yeah, lots of patents.

Katz: How many patents do you own, or is your name on them?

Perlegos: Yeah, quite a few. I don't know now.

Katz: I presume there were some at Atmel, as well.

Perlegos: Yeah.

Katz: Well, let's start getting to Atmel now. How come in 1984 you decided it was time to leave SEEQ?

Perlegos: Okay. We had money, but it was mostly diluted. It was mostly that Gordie left and I sort of followed.

Katz: And he left because he wasn't getting along with the VCs. So, you followed Gordie?

Perlegos: I followed Gordie. We started a new company. Before we started Atmel, we developed Chips and Technology. If you remember, go back, and Chips and Technology was the first company to pioneer graphics accelerators.

Katz: I remember, and they were very popular, very successful in a short time.

Perlegos: Yeah. I developed Chips & Technology with Gordie. I used to own one third of that company. But somehow, I guess, something happened, and I didn't stay at Chips & Technology. I left after six months. So, I gave it all up and I left and I went and I formed Atmel.

Katz: I think there was something happening at Chips & Technologies that was a very important piece of Atmel, and that was they didn't have a fab. Tell us about that. That was a major departure for any semiconductor company at the time.

Perlegos: Well, that was the idea. So, what I just said earlier, you know, why I left SEEQ. You develop a new idea, a new technology, a new circuit, new device, but you need a lot of money to build a fab and be able to manufacture it. So, when you get so much money, you give up a big dilution. That was behind the idea of starting fabless companies at that time. We started that idea with Chips & Technology that we're going to go out and form a company that is a fabless company. So, we just needed to develop circuits and be able to fabricate those circuits in other people's fabs.

Katz: Was that your idea, Gordie's idea?

Perlegos: My idea.

Katz: Huh, interesting.

Perlegos: Yeah, my idea. So, we developed that idea at Chips & Technology, and then I did the exact same idea when I formed Atmel. When I started Atmel, I said, we're going to do exactly the same thing. We're not going to develop a fab—we're going to concentrate on making circuits. You know, we didn't have the money to [make a] fab.

Katz: What made you think there would be available capacity at other people's fabs?

Perlegos: Well, I went around and I asked, right? I visited many companies and I asked them. I was able to do that.

Katz: Where did you find it, for both Chips & Technologies and later for Atmel?

Perlegos: For Chips & Technology, I don't remember where I found it. But for Atmel, I know I found it at General Instruments. I went to New York and I talked to the people in General Instruments. They had a fab both in New York, Long Island and in Arizona. They were doing some microprocessors at that time. They were doing the PIC microprocessor. They were also doing some memories. I said, "Okay, you know, I'm very good. I can develop lots of different products, and I will let you license all the products I develop, but I get to sell them as well, and you sell them. I sell them, but you manufacture them and I buy them from you." And the guy said okay. So, we sat down together and he says, "Okay, what are good products to develop?" We had about 10 products that we were going to develop, and we started developing them. They also gave us, I think, $5 million. They didn't give us $5 million up front. We had to develop the product first, deliver it, and then they would pay us so much money for each product, and that's how we started out. The person I negotiated the agreement with was Morris Chang who was president of General Instruments at the time and later left to start the Taiwan Semiconductor companies TSMC and UMC.

Katz: They paid Atmel for the designs.

Perlegos: For the designs and for the right to manufacture and sell them.

Katz: And how did you pay them back? Just with giving them access to the designs, right?

Perlegos: That's right. They had the right to sell them anywhere, and we had the right to sell them anywhere, because, you know, for me, always the idea is, every product is a big market. So, more than one player can play in each one of these products.

Katz: You had to start the company on a shoestring, then, because you didn't have any revenue yet.

Perlegos: Yeah, no revenue.

Katz: And you had to have a team big enough to do all those designs.

Perlegos: I just got married, just had my first kid, no salary for me, *<laughs>* so it wasn't easy. People today want millions of dollars to start a company. They want to feel happy, but that was not the idea.

Katz: What was the investment in Atmel at the very beginning?

Perlegos: Well, my wife didn't speak very good English, so I convinced her to sign up on the house as mortgage collateral, and we used that—I think we were able to borrow a few hundred thousand dollars and start the company that way.

Katz: Oh! That is a shoestring! And then ultimately, though, you were able to build some parts and sell them…, and effectively pay for the production capacity to General Instruments with the profits from those parts.

Perlegos: That's right.

Katz: Which I presume snowballed the company up. Was Atmel immediately successful?

Perlegos: Atmel was successful, but Atmel ran into a big, big legal [issues and] litigation. Because I was very successful, everybody was after me. We had lawsuits from everybody. We had lawsuits from AMD, from Intel, from the ITC, from you name it, we had a lawsuit. Everybody was trying to stop us. *<laughs>* One time, I believe, we had five lawsuits going at the same time.

Katz: So, what was the bigger expense, R&D or legal?

Perlegos: Everything was a big expense.

<Laughter>

Katz: All right, so, you were making products using General Instruments, a US company. How did the ITC get involved?

Perlegos: ITC got involved a little bit later. I believe after General Instruments, I don't remember exactly where it came in. With General Instruments, we were so successful, the products were successful, they liked the product so much they told us, “Okay, you guys cannot sell them anymore; we're going to keep them.”

Katz: Ah, so they stopped supplying you.

Perlegos: Stopped supplying the wafers. Then we had to go overseas. I went to Japan and I started in Tokyo. And I went all the way down to South Japan and stopped at every fab in Japan. I talked to everybody one day at a time. There was one that agreed to commit on the spot to sign a contract to manufacture our products, Sanyo.

Katz: Sanyo. Ah, then, that would be the reason why the ITC could get involved later, because you were importing things from Japan.

Perlegos: That's right. So, then the ITC got involved. GI kept the chip circuits we had developed.. They were making them. Later they changed their company name to Microchip. That's how Microchip got started, partly as a result of other products that Atmel had developed.

Katz: Those were only nonvolatile memory products, or others as well?

Perlegos: And the PIC microcontroller products that they had originally. But we continued making our memory products at Sanyo, and they were successful.

Katz: I was aware that the main lawsuit against not only Atmel but anybody who made EPROMs, came from Intel. And that Atmel is probably unique in beating that lawsuit from Intel. All the others had to cave in and either stop building them or pay a big royalty.

Perlegos: What happened is, so, you can say I have been very successful. What happened is that, my idea was good, but it was so successful that the GI guy got jealous and he didn't give us wafers, okay? So, then we went to Japan, and we were making wafers at Sanyo. Again, we were so successful at Sanyo that ITC stepped in, and they stopped us [from importing our products].

Katz: Why would they?

Perlegos: We could not import wafers, because they were patented [by Intel]. Some of the wafers were non-volatile memory wafers, and some of the original non-volatile memory patents I had developed at Intel could not be utilized to import non-volatile memory products by anyone except Intel.

Katz: So, Intel decided to stop you.

Intel got the ITC to stop you.

Perlegos: That was no big deal for us, okay. We said, “So, you don't want to allow us to make wafers overseas. We'll make wafers in US.” So, we went around and we searched and we found a fab in Colorado. We bought the Colorado Springs fab from Honeywell, and we started making our wafers there. We stopped making with GI, stopped making with Sanyo, and we started making our own wafers in Colorado. So, then the company started—

Katz: So, then the ITC had no jurisdiction. And did that cut off Sanyo? Were they happy or sad about that?

Perlegos: That was an unfortunate thing, but business had to continue.

Katz: Right. Well, even if you hadn't started in the US, you still would have had to stop with them because of the lawsuits and the ITC. So, how did you beat that ultimately? Beyond having local manufacturing, you ended up with something good from Intel.

Perlegos: Yeah, one good thing about all this negotiation with Intel, we were able to license some of the Intel microcontrollers.

Katz: Why would they let you do that?

Perlegos: Well, Intel always liked me, so— <*laughs*>

Katz: That's a reasonable answer, but I'm not sure it's the only one.

Perlegos: We were then the first company to make—I guess I can say this was a marketing direction. We were the first company to make Flash-based microcontrollers. Microcontrollers up to that point were getting utilized in everything. Anything and everything had a microcontroller. But they did not have a memory that you could program and erase on board. We were the first company to pioneer an in-system programmable Flash microcontroller, and that gave us a big success. Atmel had been successful initially, because we developed a lot of non-volatile memories. Its next success, you can say, was that we developed Flash microcontrollers. And everything today is Flash microcontrollers.

Katz: Those first microcontrollers were the Intel 8051.

Perlegos: 8051, yes.

Katz: And why did Intel allow that to happen?

Perlegos: Well, it was a settlement, a cross-license. We paid some money, and it was a settlement, and Intel's main objective was to stop us from making wafers overseas. But they did really help to push us to make wafers in US. You can say that. They didn't care about that.

Katz: I had a recollection that there were some of the intellectual property that came with the Honeywell acquisition was a valuable negotiating tool with Intel.

Perlegos: Yes. When we bought Honeywell's fab, we also got many patents from Honeywell. So, we were building up our patent portfolio. We had [rights to] many patents from GI, from [when] we were making products at GI, GI also had a lot of patents. The Honeywell patents, the GI patents, the US fab—really, the US fab helped us a lot in negotiating a settlement with Intel. But the Honeywell fab also gave us the starting point to build up a large patent portfolio, as well, which helped us grow substantially.

Katz: So, the original fabless company bought their own fab and became a fab company. That was a major change in the philosophy. We were talking about the beginning of Atmel, which became originally a fabless company and later evolved, through not necessarily their own desires but with good results, to became a fab company. The first products at Atmel were memories, as you had done at SEEQ. How did you decide to evolve to other things as well?

Perlegos: Well, you know, Atmel was formed to develop CMOS memory, mostly E-squared and Flash memories. We were successful because we were able to sell a lot of products to telephone companies like Nokia, Motorola—

Katz: Had anyone else done CMOS non-volatile memories up to that point?

Perlegos: Probably, I don't remember, but we were able to make them smaller, faster, and much better technology in CMOS. I believe after that, many people followed, but we were the, you can say, the leaders in that area at that time. So, that's how Atmel got started. So, then, with the license that we got from Intel, we pioneered the Flash microcontroller that became now a standard everywhere. Any microcontroller that is designed today has a Flash memory inside.

Katz: We know that there had been Flash developments earlier than when Atmel did it, at Toshiba. And about the same time Atmel did it, Intel was working on it too.

Perlegos: Yes, everybody.

Katz: What was the motivation for Flash memory as distinct from E-squared or EPROM?

Perlegos: The motivation for Flash memory is to have a much bigger density. We had computers which required a certain amount of non-volatile memory. The memories were not so big, as we only stored the BIOS in them, okay? Then the mobile telephones came on board, and they required huge amounts of non-volatile memory. You store the whole program of the telephone on board, so they had to have a memory to store that program. So, that's how the development of the Flash memories became more and more important.

Katz: Flash memory was able to get higher capacities or densities. Why was that, and how did Flash memories become denser than, say E-squared or EPROM?

Perlegos: In Flash you didn't require all these organizations that you had in E-squared, the organization was a little bit different. Also, we were able to compact the cell size and the technology was much better, so we were able to put more bits on a silicon [chip].

Katz: Well, as I recall of my time there, E-squared was always a bigger cell size than the EPROM or the Flash and, therefore, E-squared was not financially competitive with Flash or EPROM, for large capacity program storage applications.

Perlegos: Yeah, E-squared, you know, the organization was a little bit different. We had to organize 8 bits at a time. When we went to Flash, we could organize it one row at a time, which was fine for program storage. So, we could take out a lot of extra circuitry that we had on board for E-squared, and we could use more than 8 bits to program and erase. The overhead was much, much smaller. So, this way, we were able to make much bigger memories, and we called them Flash memories. We were very successful in cell phones, in companies like Motorola, Nokia, at that time.

And then, we were also very successful in microcontrollers. We were able to put two kinds of memory in them. We put a little bit of E-squared so people could use it to change system data. Let's say if you want to store how many times you used something, you could write it into the E-squared. The microcontroller was able to do its own writing, so that was an important feature. And then, you could store the program that people write how to run the microcontroller, into the Flash memory. So, we had two types of memory on the microcontroller, a little bit of E-squared and a big Flash Flash Memory.

Katz: The major difference that I recall was that the E-squared with its byte organization was able to change any given byte, whereas the Flash or the EPROM could not. It could read any given byte, but it had to change a bunch of them at a time.

Perlegos: Yeah, you had to change a whole row.

Katz: Which is okay for the program, because you do that infrequently, but not for the working data.

Perlegos: And this continues on today. So, today in a Flash, people can erase a whole block.

Katz: Yes, which means—implies that even today, to save small bits of data, they need a something that's like an E-squared.

Perlegos: That's right. So, that was another area where I was able to help the development. At Atmel, I think we developed one more important thing. We said we developed the CMOS memories and Flash memories and then the Flash microcontrollers with the help of Intel. We did not develop our own microcontroller [at first]. Eventually, we developed our own microcontroller with the AVR. We did the AVR Flash microcontroller. But another big thing that I believe we need, or I need to take credit or you need to take credit or one of us has to take credit for, not too many people know about it, is that we were the first company to develop—We were selling Flash to telephone people. Then we were able to convince these people to use the ARM microcontroller. We developed the ARM and the analog for the cell phones. So, we acquired the company in France, ES2, [European Silicon Structures] who had the ARM microcontroller, and we developed all the analog that—

Katz: The ES2 people already had an ARM license?

Perlegos: They had an ARM license. Then we were able to develop all the analog blocks that the cell phone needs to operate, and combine them with the ARM microcontroller. We were selling millions of these devices into cell phones using the ARM. So, we were probably one of the first companies that was very successful [with ARM and analog] at the time. There were other people like TI and so forth, but we were also one of the pioneers in this idea, utilizing ARM in cell phones.

Katz: So, to recap, there was an evolution there, in the product line going from pure memories to mixed memory with micros, and then later to adding analog functions to that micro, as well.

Perlegos: That's right. Today, all cell phones use ARM, but, remember, it all started back there.

Katz: I'm curious about how you managed your personal career activities in switching gradually from pure engineering to corporate management. You were reasonably successful doing that, but not all engineers can pull it off. How did you do that?

Perlegos: Well, you know, I had—you could say I had a lot of training, so—

Katz: Who were your teachers?

Perlegos: Being a technical guy, you can be very successful as a CEO.

Katz: Well, you've got a lot of different problems as a CEO than you did as an engineer, though.

Perlegos: That's right, but if you have the engineering ability to solve problems, then you use that to solve the CEO problems.

Katz: That's, I think, a good formula.

Perlegos: But the other way around doesn't work. If you're not an engineer and you're a CEO, you cannot go back and—

Katz: And be the engineer, yeah.

Perlegos: And that was one advantage I had. I think it was very helpful that I had a good understanding of the technical problems, technical issues. I was able to understand what people were trying to develop and things went much smoother.

Katz: But you still had the issues of funding the company and dealing with the large organization, especially when you had acquired companies that are geographically separated. How did you manage to cope with all of that?

Perlegos: I believe I had a unique management style. I hired a very good professional people, like yourself, or like other managers, and I gave them the responsibility to run it. I depended on people that knew how to take care of certain aspects of the organization, and I allowed them to do it. I believe that was very successful. I did not micromanage an area. I—

Katz: Well, that's true. I will attest that I never felt micromanaged working for George.

<Laughter>

Perlegos: So, it was working well all around. I think it worked most of the time.

Katz: Well, describe some of their early—

Perlegos: So, having the understanding between technical and hiring good management people was very key to the success.

Katz: Can you describe some of the non-engineering problems that Atmel faced and how you went about solving them or having your team solve them?

Perlegos: Oh, well, I had many, many problems. We grew to 10,000 people. The technologies, the products were very successful, so we had to have more fabs, more capacity. We had to raise money all the time to build new facilities, going to different areas. The biggest problem for Atmel was to migrate away from being a memory company into other areas and make sure that its revenue was coming from the other areas. There were many problems, but I think we were working and solving most of those issues.

Katz: Atmel was also fairly unique, or at least unusual, in that for many of its early years, it made a profit every year.

Perlegos: That's right, yeah. The company was very successful from the beginning.

Katz: To what do you attribute that?

Perlegos: Um, good management. *<laughs>* Good managers, good technical people. You know, everybody was doing their job. As I said earlier, I believe, at Atmel we had good technical people, good management people that were executing and getting things done. I think even from the beginning, if you look at the original Atmel business plan, the first five years, the first ten years, we were able to meet those targets pretty fair on, and we were very successful in diversifying the company into other areas so that we always had a new area to grow as the market for those kind of areas came into existence. Like I said, we bought ES2 that had ARM microcontrollers and analog that allowed the company to grow substantially into a different area, than we had originally. That was one good example.

Katz: Many of those acquisitions came with manufacturing capacity.

Perlegos: Yes.

Katz: It has been observed, partly by me, partly by others, that ultimately Atmel had too much capacity.

Perlegos: That was one problem that not only Atmel faced, but many companies face. As the downturn came and we had too much capacity, we were not able to utilize it, and that dragged the company down.

Katz: Eventually the company stopped being profitable for a while. So, the question I have for you is, what advice would you give to another young company who wants to be in manufacturing, on how to balance the capacity for manufacturing to account for growth, without overcapacity for the down times?

Perlegos: I think that advice is not good anymore, because those kind of days are over. The cost of creating [semiconductor] manufacturing nowadays is so expensive that it's very, very difficult for companies to get into these kind of areas.

Katz: And if you try to buy the capacity, it possibly may not be up to date.

Perlegos: The technologies are changing. One problem that Atmel faced, as well, is the technology changes, every year, every couple years, and you need new technology, new fabs, new equipment. Everybody is going through this problem.

It takes huge amounts of money to keep up.

Katz: So, the advice you would give, then, is don't be a fab company again.

Perlegos: <*laughs*> Yeah, go back to the original idea of Atmel, which most of the companies are following today, anyway.

Katz: Well, that makes sense.

Atmel eventually, as I said, wasn't quite as successful, possibly, due to the extra cost of all that extra capacity. How did you cope with that big problem?

Perlegos: Well, we closed some of the fabs down. We transitioned to new areas, like we had transitioned to microcontrollers, and we had transitioned to other products that were able to utilize some of the capacity. So, we were successful that way, trying to balance the amount of capacity. Remember, Atmel grew substantially supplying a lot of chips to cell phone companies, and cell phones were very successful. They had projections of millions of units.

Katz: Ultimately billions.

Perlegos: Yes, and Atmel was developing technologies to be able to supply some of those customers we had. They were demanding that we put in place the capacity to support them, and we did that. But their forecasts didn't come through. And Atmel had to downsize just like they did and move on to other areas to make products in other areas. It was an interesting problem just like we were facing today, that's the thing that has to be planned, forecast very accurately, to be able to forecast what the markets are going to do, what the products are going to do, and be able to put the capacity in place to meet those demands. It's a very, very difficult problem.

Katz: Indeed. And some of the diversification directions were more successful than others. What would you say were the more successful new product areas or acquisitions that Atmel made?

Perlegos: Like I said, I think going into a microcontroller area was very successful. Pioneering the Flash microcontroller was very successful. Going into ARM microcontrollers and analog circuitry was very successful. There were many areas that were successful. Not every one. We had to try out many areas.

Katz: There also were the smart card and the biometrics and the automotive things.

Perlegos: We tried many areas to get into different applications. Not all of them were successful, but many of them were very successful.

Katz: Okay, well, in a few minutes, I'd like to start closing up with a discussion of future activities and directions for your life as well as advice for young people. But before we do that, I'd like to kind of recap some of the contributions you have made and make sure we get them covered. So, let's see if I can remember some of them. One is in early times at Intel, you helped develop NMOS, nonvolatile memory.

Perlegos: The biggest contribution that I made is that I developed the N-channel—I developed the nonvolatile memories, you can say, with the help of other people, but that was a big contribution to the industry and to Silicon Valley and to everybody. We developed the N-channel nonvolatile EPROM memory. The first device that we developed was the 2708, that utilized a brand-new technology at the time, which was channel injection and two layers of poly. Remember, previously the 1702 EPROM came in the P-channel technology that was done before. It came in as a two-transistor cell. Here we were able to utilize two layers of poly, channel injection, and develop all the circuits needed, sensing and everything else to develop a single transistor cell 2708 memory that matched the microcontrollers.

Katz: And the main industry impact it had was that you could keep up with the demand for microcontroller program capacity.

Perlegos: We created a new industry. Like, DRAMs, now there were nonvolatile memories, and infinite amount of growth like the DRAMs. So, that was the beginning of the non-volatile memories, EPROMs, E-squared, Flash memories. That was their base. Everything that is done today was developed back then in 1974.

Katz: Okay, then, later, by the early '80s, you were working not necessarily at Intel, but with the SEEQ group departure, you were working on 5-volt-only, which, again, expanded that non-volatile memory market.

Perlegos: At Intel we developed the—not only the EPROMs, we developed the E-squares, or I developed the first E-squared, 16K E-squared memory, using 100-angstrom oxides. We were using tunneling, a completely new technology, which didn't exist before in any device on any memory.

Katz: And in what applications did that have a major impact?

Perlegos: In microcontrollers.

You were able to utilize, read, and write these memories on-board without taking them off the system to change its memory content, okay? So, then after I went to SEEQ Technology, I developed the 5-volt-only memories, non-volatile memories.

Katz: They were still NMOS, right?

Perlegos: Still NMOS, yes, 5-volt-only was a big, big advantage. I mean, if you say this non-volatile memory is huge, billions and billions of dollars. It started up in 1974 with the EPROM and then it continued with the E-squared development and then you can say the nail on the coffin was done at SEEQ when I developed the 5-volt-only circuits, memories with charge pumps to be able to operate this device with only 5 volts on board, okay? You had a device there that can connect to any system, any memory and be self-independent. So, that was a big, big, big development.

Katz: So, another big contribution to the industry.

Perlegos: Big, big, big contribution.

Katz: As I recall our conversation a little while ago, the next major evolution that you contributed largely to was doing it in CMOS at Atmel.

Perlegos: Yes.

Katz: And also at about the same time inventing the fabless concept for semiconductor companies.

Perlegos: That's right. And expanding the Flash memories so they would be utilized in cell phones, then taking these Flash memories and putting them in microcontrollers and creating the Flash microcontrollers.

Katz: Ultimately, then, adding into that capability the more competent microcontrollers made by the ARM designs.

Perlegos: That' right. That's a later on development we pioneered.

Katz: I just want to remark that in doing all those technical things, you were also able to bring three companies to life using venture capital and ultimately bringing them public, which is another major accomplishment, in my view.

Perlegos: That's right. We brought SEEQ [public]. I was a co-founder of SEEQ Technology. We started it in 1981. We used venture capital and big venture capital money from Kleiner Perkins, and we took it public in 1983, very, very, very major accomplishment at that time. And then started Chips & Technology. I didn't stay there for very long, only six months, but that company also went public and was very successful. And then, Atmel was a big success. We started that company. We took it public. It grew to billions of dollars. It had 10,000 people at its peak, so it was a very major company.

Katz: Thanks for the recap of those accomplishments. Let's ask now, what have you been doing since your ultimate departure from Atmel several years ago?

Perlegos: I sort of now have pretty much retired, and am trying to do all the things that I didn't do while I was working inventing all these things. Also, helping my kids. I have three kids. One is an engineer. The other one is going through medical school, so we're helping him out. And my daughter started university and is going to UPenn. So, we spend some time going around making sure they are okay.

Katz: Well, that's always fun to do. It's nice to watch your family blossom. Do you have any other projects in the technical areas?

Perlegos: No, no projects right now. Mostly concentrating in taking care of things at home right now. Maybe once the kids grow—

Katz: Home is both here and in Greece. How do you split your time between them?

Perlegos: Well, we spend most of the time here, but for holidays, summertime, it's always good to go back to Greece, because I was born there, my wife, Angela, is from there, and we go back every summer and visit the place.

Katz: Well, good.

I'd like to close with asking for your thoughtful advice to other young people than your own children, who want to be involved in innovative product development, which you certainly have had experience doing.

Perlegos: Well, you know, I have to give the same advice I have given out in many interviews, and that is that even though you see the world getting bigger and bigger, the inventions getting bigger, and you think that there is nothing else out there, there are always ideas. You just have to set your mind to it, and you always have to think that you can do it. You have to try to do it, like I had done in the past. All these ideas didn't even exist, and people never even thought about them. Young people have to work on them and create them, because the world is changing, whether it's hardware, design circuits, software. Everything is changing, and it's going to change, nothing is going to stand still. So, if you are there and you want to be part of it, you have to work at it, and you will be successful. If you work at it, you will be successful.

Katz: What kind of education should every young person have then, Engineering? Finance? Marketing?

Perlegos: Everything is good nowadays. Marketing is good, finance is good, engineering is good, software is good, so any of those areas, you can be very successful. But get the maximum amount of education. Remember, I have been very successful. I went to the university four years at San Jose State and almost six years at Stanford University, so things don't come easy. So, you need some education behind you. Don't think that you can come up with things, just because you see one idea you think you can do it. It takes time, and it takes work.

Katz: Indeed it does.

Perlegos: *<laughs>*

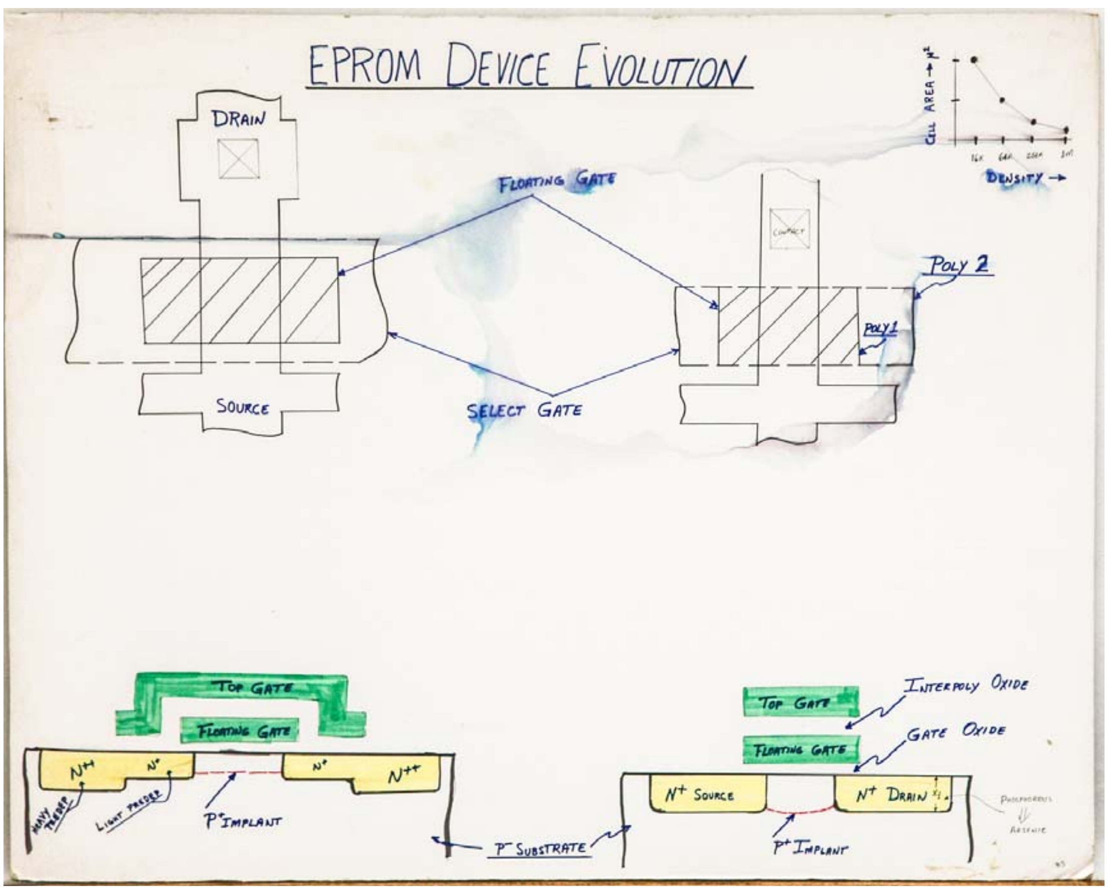
Katz: Well, with that, I think we will close and say thank you very much for your participation. This ends the interview.

END OF INTERVIEW

APPENDIX

Katz: As an appendix to George's oral history interview, he's agreed to demonstrate some of his early contributions technically with original diagrams that were used, I presume, in the Intel and/or SEEQ era that describe some of the technology innovations in which he participated. Take it away, George.

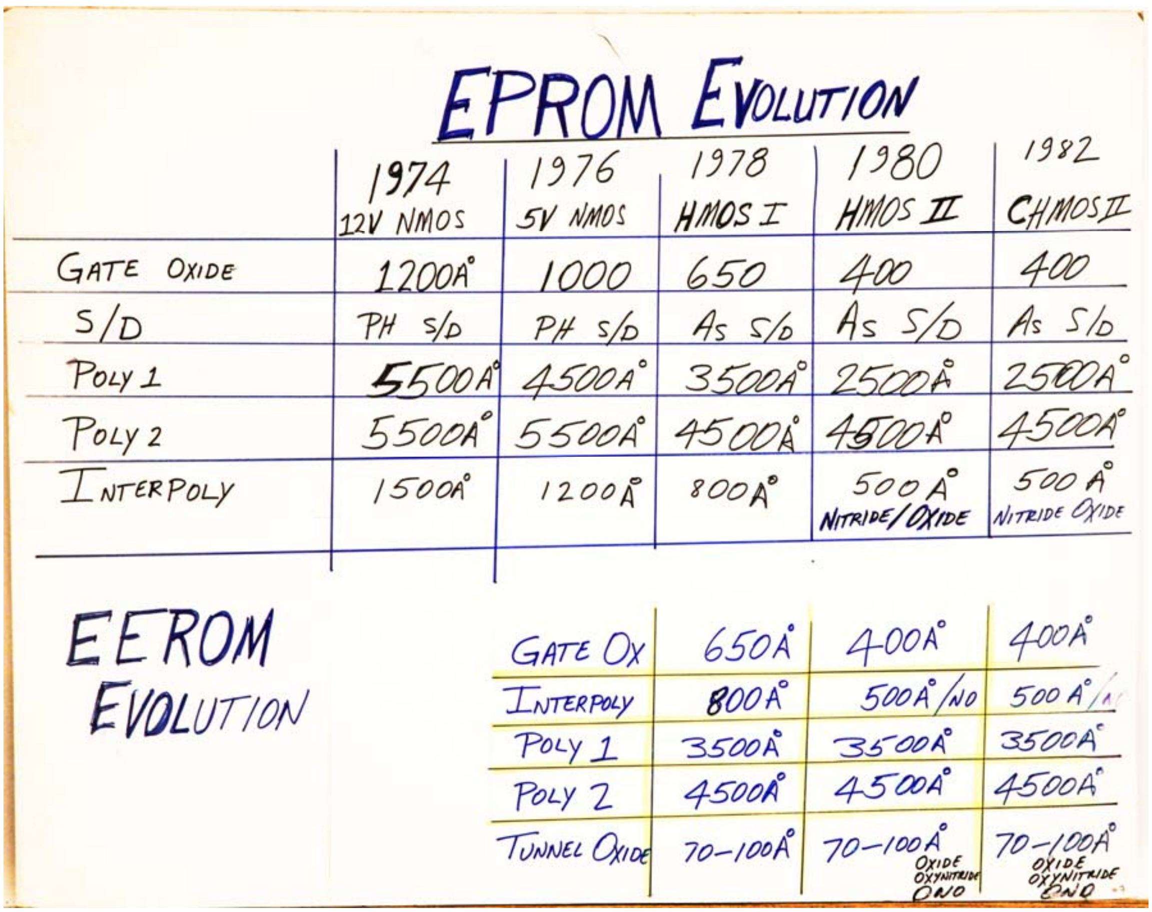
Perlegos: Hi. Here very quickly, this shows the original development that I did in EPROMs. Here we have <*referencing image below*> — we developed the N-channel EPROM that we talked about in the interview. It's a two-layer poly. We were able to make a single-transistor nonvolatile memory [cell] that did not exist before, with two layers of poly. You see it here, and this is what it looked like. Then, the next evolution of the EPROM was that we were able to make a much smaller device but only with 5 volts. This [original] one had to operate with -5 in the substrate, and +5, +12 volts. We developed the ion-implantation technology, and we developed the silicon poly-edge technology, self-aligned technology. We were able to self-align the gate. So, the gates [on the left], you can see, go over, because the [self-aligning] technology did not exist. Then we developed the technology [on the right] to self-align the gate, and we developed a smaller single gate, and we put the implant in the channel to be able to program and create the hot carriers, hot electrons, much easier.



Perlegos: So, these are the two EPROM innovations that I did, we put the channel implant in the channel to make more carriers at lower voltages, and self-align the gates to make the cells smaller. Here, it shows you the cell compared to that one. It's much smaller. It shows you the cell area as it started getting smaller and smaller as the technology evolved over time.

Katz: The self-aligned gates, was that a unique development for EPROMs, or did it exist for other products, as well?

Perlegos: EPROMs. We developed it for EPROMs, the implant layer. We utilized it for EPROMs at that time, okay? So, just quickly, <*referencing image below*> we started out in '74 with 1,200 angstroms of oxide. When we developed the 5-volt EPROM device, we went to 1000-angstrom oxide, and then on and on. By 1982, we were down to 400-angstrom technology as the technology evolved. And then, we had two layers of poly always.



EPROM EVOLUTION

	1974 12V NMOS	1976 5V NMOS	1978 HMOS I	1980 HMOS II	1982 CHMOS II
GATE OXIDE	1200Å	1000	650	400	400
S/D	PH S/D	PH S/D	As S/D	As S/D	As S/D
POLY 1	5500Å	4500Å	3500Å	2500Å	2500Å
POLY 2	5500Å	5500Å	4500Å	4500Å	4500Å
INTERPOLY	1500Å	1200Å	800Å	500Å NITRIDE/OXIDE	500Å NITRIDE OXIDE

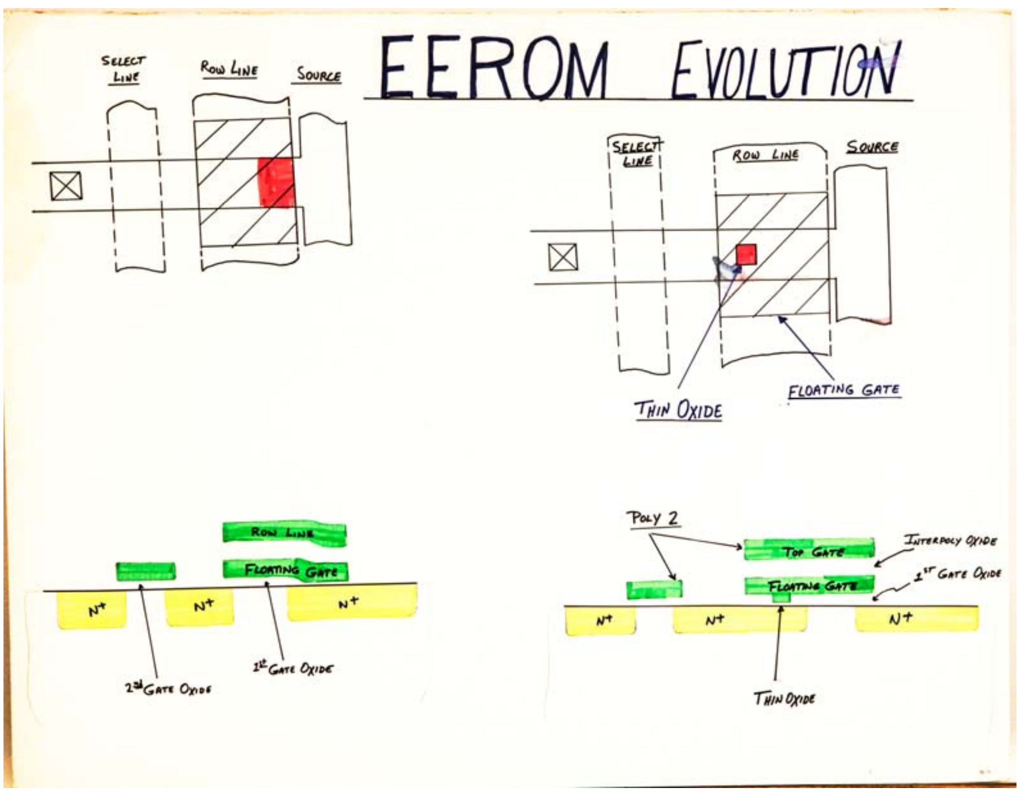
EEROM EVOLUTION

GATE OX	650Å	400Å	400Å
INTERPOLY	800Å	500Å/NO	500Å/N
POLY 1	3500Å	3500Å	3500Å
POLY 2	4500Å	4500Å	4500Å
TUNNEL OXIDE	70–100Å	70–100Å OXIDE OXYNITRIDE ONO	70–100Å OXIDE OXYNITRIDE ONO

Katz: Ultimately, they became self-aligned, too.

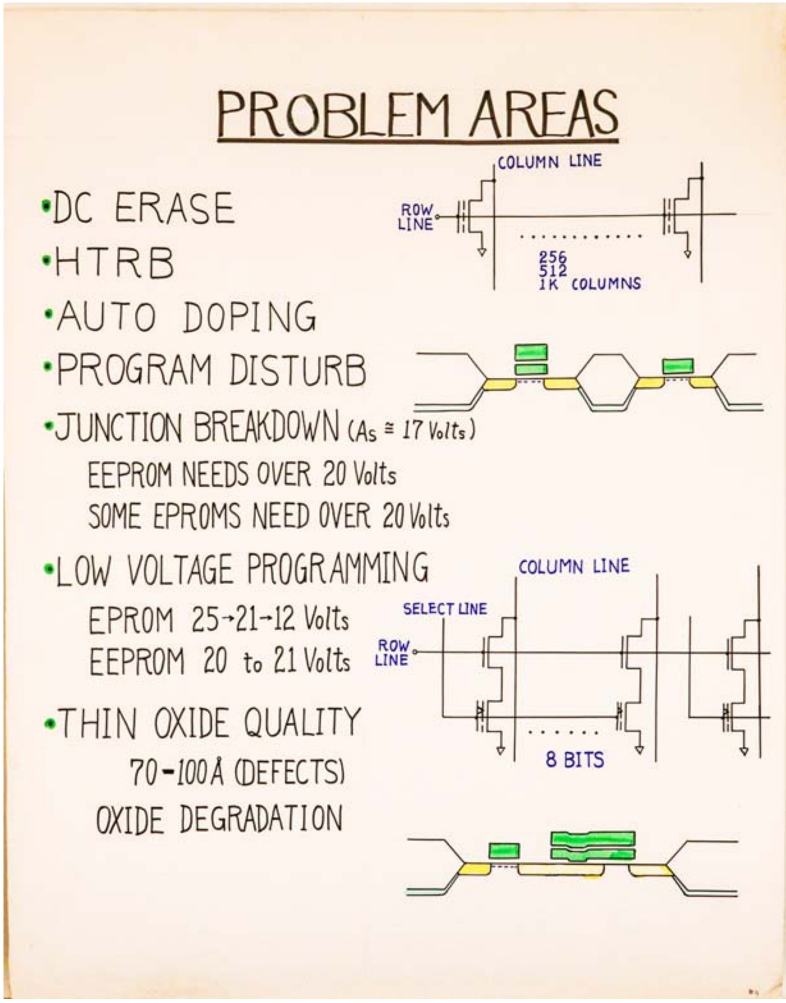
Perlegos: Yeah. The other thing that helped us, remember, we had two layers of poly. We had an oxide below the first poly. We had an oxide between poly to poly, and to make the voltages smaller and smaller, we had to also reduce the inter-poly oxide [thickness], and then we were down to 500 angstroms over time. So, this technology evolved over time.

<*referencing image below*> The next development that I contributed on was the E-squared. In non-volatile memories we went from EPROM to E-squared, and this was the original E-squared device. This is what it looked like, where in this thin area [under the floating gate], we were able to grow the 100-angstrom oxides so we could get the tunneling done. Eventually, we put it in the middle. You can see we had two layers of poly self-aligned with a thin oxide and a pass gate. The difference between the EPROM and E-squared is in EPROMs we were able to make a single transistor cell, E-squared we had to have two gates to make the memory cell.



Katz: And that made the cell sizes bigger than the EPROM.

Perlegos: Yes. The next contribution that I made is that here <*referencing image below*> we created a completely new technology, a new industry, I guess you could say. The nonvolatile memories became a new industry in Silicon Valley and it's still today with EPROMs, E-squared, and Flash memories. But all these had many, many problems. Here is the list of some of the problems, like it had DC erase, it had HTRB, auto-doping, program disturb, junction breakdown—and more.



Katz: You explained earlier, DC erase was the disturbing one cell while you're writing the other.

Perlegos: You are disturbing the cell adjacent to it. So, we had to solve those problems.

Katz: Let's describe HTRB, if you can.

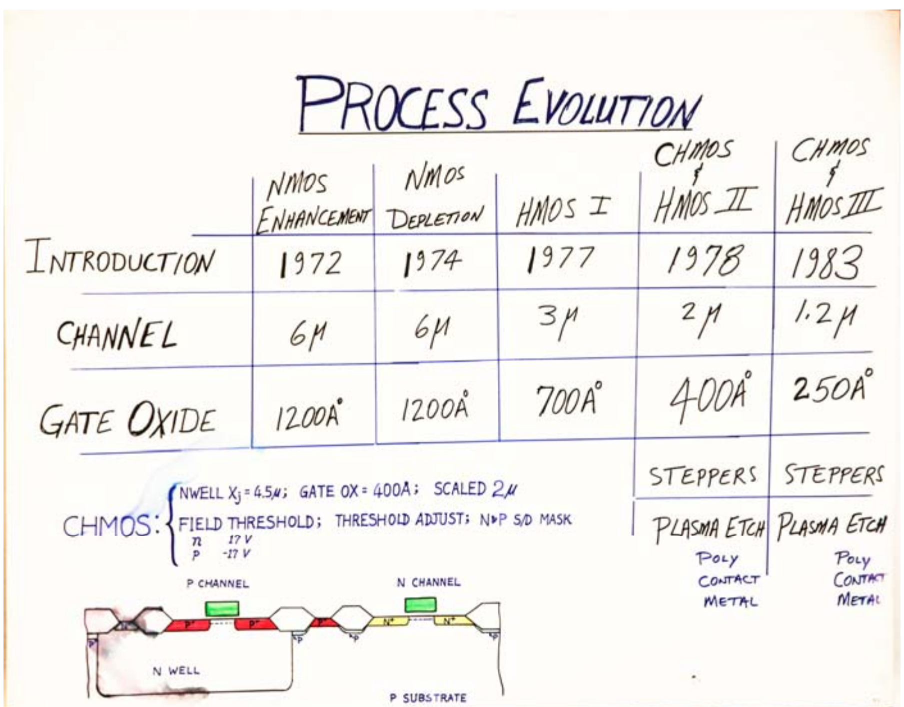
Perlegos: This is High Temperature Reverse Bias.

Katz: What was the problem there?

Perlegos: Many problems. <*laughs*> I don't remember exactly right now, but all these memories had to survive with— we had to bake them at 250 degrees [to accelerate aging]. They had to survive and retain information for 10, 20 years. These were other problems that we had to solve:. While doping one area, we were [automatically] doping the other areas. And programming disturb is a similar problem but a little bit different. Anyway, these are some of the problems that we faced in making EPROMs and E-squared memories and Flash memories.

Katz: I'm curious about the one at the bottom, the thin oxide quality, which was very important for E-squared.

Perlegos: Yeah, remember, at that time, when we said earlier, the technology in 1974 was 1,200 angstroms, 700 angstroms. That was the best technology available in the industry. So, here we come, or I come, and we say we are going to make a memory using— <*Referencing image below*> So, here we come and we say we're going to make a memory, a very successful, reliable memory using only 100 angstrom [oxide], whereas all the other technologies that were done at the time were 1,200 or 700. That was the time that we did it, '77. The technology, oxide technology that was done at that time was 700, and here we come and we say we're going to make a memory that is 100 angstroms, leaps and bounds in evolution in order to make it happen.



Katz: And how did you achieve that? You had to have special fab processing?

Perlegos: Special fab processing, special techniques in growing the oxide, and a lot of people in the fab developed some of these techniques, so it was a lot of hard work. This was done at Intel.

Katz: So, you did have access to the fab people.

Perlegos: Yeah, this was done at Intel. All of these inventions I did were done at Intel.

Katz: And you were able to transfer that knowledge to the other fabs when you were a fabless company?

Perlegos: Yeah, by that time the—when I left Intel in 1981, you know, many of these technologies had evolved, so.

Katz: Well, thank you for that update, and I'm intrigued by the original documents that you've been able to preserve for all these years.

Perlegos: Thank you.

