Oral History of Chenming Hu

Interviewed by:
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Peggy Aycinena: Excellent. So hello to our audience. And I'm so delighted to have a chance to interview Professor Cheming Hu today from UC-Berkeley. I will introduce myself, I am Peggy Aycinena. I'm a journalist working out of Silicon Valley. I cover the Electronic Design Automation (EDA) industry. It's my great honor to be here today to talk to Professor Hu. Professor Hu and I had a chance to be on stage at the Design Automation Conference in Austin in June. And Professor Hu was specifically there to receive the Phil Kaufman Award, an annual award for lifetime achievement that is given by the EDA Consortium, and also the IEEE CEDA, which is the IEEE organization that interfaces with the EDA industry, Electronic Design Automation.

I'm going to read briefly from the press release that EDAC released in April of this year, when Professor Hu was named the Kaufman Award winner. I'm going to just take a couple moments to read the first several sentences. Professor Hu is being recognized for his contributions in device physics, device modeling, and device reliability through BSIM and BERT models that have transformed the semiconductor manufacturing and electronic design automation industry. Professor Hu's team invented the revolutionary-- quite revolutionary, those are my words-- 3D FinFET transistor structure that simultaneously achieves size and power reduction to enable continued scaling of the microelectronic chips. And as we all know, the scaling is the name of the game in everything semiconductor.

So with that very formal intro we're going to talk and have a conversation. Let's start with the Kaufman Award and let me ask you something that we hadn't talked about. But let's do it anyway. Were you surprised to be named Kaufman Award winner?

Chenming Hu: Of course I was surprised. I do have many friends in the industry. And knowing how important it is to have friends to become nominees of honor, I guess I wasn't as surprised as otherwise I would be. But still it was a great surprise.

Aycinena: Well, I think it's appropriately called the Nobel Prize in electronic design automation. And certainly your work more than warrants the award. I will say that Dr. Wally Rhines, who is the CEO of Mentor Graphics, has joked over the last few years that it was very Berkeley-centric. And he is a Stanford man, so you are carrying on in a great tradition-- that the Kaufman Award seems to gravitate towards Berkeley. And well done. Well done, you. Let's talk about Berkeley, but first, let's go backwards a little bit, as we have talked about in the past about your childhood, where you were born, and your journey into technology. We can touch on that briefly, if you wouldn't mind. So I turn the mic over to you briefly to let you tell us about your childhood and your decision to study technology.

Hu: All right. I was born in Beijing, China, just before the communists took over the country. My father was an Air Force man fighting on the other side, for the Nationalists. So in 1949, my mother took three children to board a boat by climbing up a rope ladder, as she described to me later, with me on her back, and moved to Taiwan. Then, Taiwan was a relatively poor agricultural country. And I recall that when I was a child, my father even though he was an officer in the Air Force, had a salary of about $20 US a month.

Nevertheless, I had a very memorable and wonderful childhood thanks a lot to my loving parents. There were five siblings in the household. Being poor has its advantages. To think back, I had many moments making toys for myself. I remember spending long hours pondering why, when I put a pine needle in the water, it will move forward. Because of the force created by the spreading of the resin at the end the needle. And countless other happy memories.

I entered National Taiwan University. That itself is some story. I wanted to study chemistry, because chemistry was my best subject in high school. I actually built a bit of a rocket lab in my home, in my bedroom. a bedroom I shared with my siblings.

Aycinena: That's physics, not chemistry.

Hu: That's absolutely chemistry. And although my father was a very cautious person, he actually tolerated that dangerous hobby. But when I said I wanted to major in chemistry, he chimed in. He said, you know, electrical engineering is the hottest topic. That is what the world needs. So why don't you consider studying electrical engineering?

The way to get in is you actually make a list of your priorities, your preferences, for the departments you want to get in. I said, I'm not going to get into my first choice, so I'll please my father, put electrical engineering as the first choice, put chemistry as my second choice. But little did I know I would get into electrical engineering, and very soon, would became very grateful for my father's advice. Because I failed freshman chemistry,. And I realize why I failed--

Aycinena: I wouldn't put that on the record. [LAUGHTER] That could be used against you.--

Hu: I realized why I failed. In high school, the textbook my school used hardly covered organic chemistry. And I was very good at that. Once I started to study the organic chemistry, the memorization required simply fazed me.

Aycinena: Fascinating. So, another question before we go on. Chemistry, physics, these are basic sciences. Engineering is what I sometimes call a man-made construct. How do you feel about that opinion, and what you think about studying a man-made construct like engineering versus the basic sciences?

Hu: You know, this is somewhat of a self-serving thing to say. But I really believe now that engineering is a more valuable discipline for humanity, at this time in human history. You know, scientists study the world as it is but engineers create that which has never been. And this is a wonderful gift that engineering study gives to the students and to the world.

Aycinena: Would it be overstating to say there's a foundation of optimism in engineering, which is that you actually can change the world as opposed to the basic sciences?

Hu: That is very well put. I think that optimism is really there. And when I look at my colleagues, and myself, those that have the most success tend to be the most optimistic.

Aycinena: Hello.

[BREAK IN RECORDING]

Aycinena: So Professor Hu, you were talking about your decision to study electrical engineering on the advice-- the good advice-- of your father. What was the status of that program at the National Taiwan University when you started versus the programs they might have offered in chemistry or physics?

Hu: It was a very good program. Although in Taiwan at that time, the students tend to gravitate toward science, especially physics. And this is, I think, partly because of the Nobel Prize. Everybody knew about Nobel Prize in chemistry, in physics. So those were more glamorous fields.

In the electrical engineering program, I got my first contact with the computer. There was an IBM computer. I forgot the model number. And I had so much confidence in my programming skills that every time my program didn't run successfully, I assumed it was hardware failure, and I would resubmit my program for another run. I remember, I had to take the deck of punched cards, making sure it doesn't drop on the way across the campus, and hand it to someone through a window and wait for two days to pick up my results. So that was my introduction to computers.

Aycinena: And what was your first language?

Hu: It was Fortran. And it was a useful language for me in an unexpected way. The time I received admission to Berkeley as a graduate student was a time when many departments were reevaluating their foreign language requirements. And the electrical engineering department very wisely added Fortran to the list of languages that would satisfy the foreign language requirement. So I opted to satisfy the requirement with Fortran and escaped from the dreaded German exam.

Aycinena: If memory serves, it was the basement of Evans Hall where the computer programs had to be submitted, your card decks, and you would go in there laboriously and pick up your print-out. When you were a graduate student at Berkeley, were you traipsing down to the basement of Evans or were you somewhere else at that point?

Hu: It was the basement of Evans. And not only students do that. Even professors. I ran into them and-- the names of some of them may come up later-- would do that themselves.

Aycinena: It was a place of misery, if memory serves. [LAUGHTER]

Hu: Where the hardware fails.

Aycinena: Yes, exactly. So what made you decide to come to Berkeley specifically? I think you and I talked, but perhaps you'll tell me who lured you there to continue in your graduate studies.

Hu: You're talking about going from Taiwan to Berkeley.

Aycinena: Yes, that decision and how that happened.

Hu: That's right. What lured me there was the reputation of Berkeley. And no professor sought me out. It was a university that I wanted to go very much. Berkeley, even at that time, had a more international outlook than many other universities. So in Taiwan, we knew about Berkeley.

Aycinena: You had told me that Professor Whinnery, John Whinnery-- ended up being your adviser.

Hu: That's correct.

Aycinena: Did you meet him after you came to campus? And what was it about his research that was interesting to you?

Hu: My first adviser for my Masters research was Richard Muller. And Professor Muller later became the pioneer of MEMS, or micro electro-mechanical technology. And this is the time when, at the young age of

MOS, Professor Muller was one of the professors doing research on MOS. So MOS was my introduction to the Berkeley program. However, after one year I thought, you know, I really wanted to learn more than just semiconductors. And I decided to go into lasers for my Ph.D. research. And there my adviser was John Whinnery. Whinnery was probably best known for a textbook that he wrote with Ramo, and it's called Fields and Waves for Communication.

So I studied the optical wave guides. It is about making optical circuits, really. I was trying to make modulators, deflectors, on a substrate.

Aycinena: It sounds like you could have made a right or left turn and gone into communication theory, or you might have gone into material science? But it sounds like you're stuck with the electrical engineering, which is to everyone's benefit. But did you ever consider those other adjacencies, as they call them sometimes, of material science or communication theory?

Hu: Yes, I have done that. And what I think really kept me in the semiconductor area was the first oil embargo that happened around the time that I graduated. And as an idealistic young professor, I really wanted to do something about energy. So I decided that of the knowledge I have, I could make some contribution in the solar cell area. So when I became an assistant professor at MIT, that was my area of research.

Aycinena: Before we get you to MIT, I have two questions about life at Berkeley. First of all, there's a very great cultural difference between life in Berkeley and life in Cambridge. Would you opine on the differences between those two places? Because you obviously had immediate experience between living and thinking in Berkeley and living and thinking in Cambridge. What you think were the major differences between those two geographies, above and beyond the brutal winters in Cambridge?

Hu: Things, of course, have changed a great deal. But we're talking about history. At that time, one thing I noticed very different is that MIT tend to have a more inward-looking culture. Many professors were its own graduates. On the other hand at Berkeley there was actually a rule that no graduate of EECS can become a professor until after at least three years working somewhere else.

And so that's one difference. I also noticed that MIT put more educational resources into undergraduate teaching. And that's a great strength of MIT.

Aycinena: Certainly. And I know we've gotten ahead of our story. I want to ask about how you decided to be at MIT. I don't want to forget something you have told me, which is you met someone very important in your life while you were a graduate student at Berkeley. So, who was that?

Hu: I was living in a dormitory called the International House, where 50% of the residents are domestic students, 50% are foreign students. I enjoyed it very much. One year after I had arrived on campus, one day I heard news that a group of new students would be arriving from Taiwan and Hong Kong. So a few of us decided to welcome them. And we stood in front of the entrance of International House, actually on top of the steps of the International House, and indeed, about 1 p.m. in afternoon, a bus stopped by and a couple of students came out. And I noticed one student that I would really want to introduce myself to. And it turned out her name is Margaret, and she became my future wife.

Aycinena: That is an extremely romantic story. And I think that should be in the movie. Particularly since the top of the steps International House is probably one of the most beautiful vistas, looking out and looking at the building.

Hu: And there actually is a lesson in this story that turned out to be very helpful for my career. I came from Taiwan and I speak Mandarin. That is my Chinese dialect. Margaret, although she is also Chinese, came from Hong Kong, and she spoke Cantonese. So we could only converse in English. And after we became good friends, I felt that was not very satisfactory. So I went to Berkeley's language lab that's located in the basement of Dwinelle Hall. I checked out the Cantonese language tapes, reel-to-reel tape, and taught myself Cantonese in a week. So the lesson that I learned is that the most important thing about teaching and learning is motivation.

Aycinena: We will edit my following comments out of the transcript. But I also met my husband at Berkeley. And he is an English-speaking person at first glance, but his first language was Spanish. I also spent time in the language lab at Dwinelle, helping myself to improve my Spanish so I could communicate more effectively and with greater affection with his family. So there's a lot to be said for those cross-cultural efforts. And there is motivation.

Hu: Yes.

Aycinena: So how many years were you at Berkeley before you finished? Obviously there was a Master's effort, and then a Ph.D. How many years were you on the Berkeley campus?

Hu: One year for master, and 3 years for Ph.D.

Aycinena: Excellent. Was it your intention when you were doing your Ph.D. to go into academia? Or did you think, at the time you might go into industry?

Hu: You know, I really did not have a set idea. And when I graduated I decided to apply to two places and see what happens. So I applied to Bell Labs and applied to MIT. And so I had 2 job offers. It was a toss-up.

Aycinena: That sounds like choosing between two marvelous desserts.

Hu: It really was like that. I do remember that Bell Labs offered $24,000 a year salary. And I was offered $14,000 a year at MIT. But I later figured out that universities had one advantage in recruiting good students, because the students had just spent 4 years revering their professors. And that is quite a motivation for students to go toward academia.

Aycinena: I know you were not an undergraduate at MIT. But I know there's a tremendous dark reputation that the undergraduate experience at MIT is quite miserable. And how would you think that compares to a graduate experience at MIT, if you're advising a young person today? That they do their undergraduate studies somewhere else, and then come to endure the rigors of MIT as a graduate student? Or would they dare be there as an undergraduate?

Hu: You know, I did not get the impression that life was miserable for undergraduate students at MIT. On the contrary, I thought MIT was a wonderful institution for undergraduates. There were greater resources. And it is a very good institution. I would not hesitate to advise young people to go to MIT for undergraduate study today.

Aycinena: And I will address the other dark rumor that has always swirled around MIT, is that a graduate student has great difficulty finishing there. And it seems to drag on year after year. You're a sterling example of doing a Master's/Ph.D. In 4 years. That has been a problem with the reputation of MIT. You were obviously a graduate adviser, you were a professor there. Did you find that reputation was way overblown for MIT?

Hu: You know, I think there's more truth to this second rumor than the first. But I did not find it to be excessive. Professors are demanding and-- by the way, I believe MIT has wised up. And the time of study is pretty much even now for all of the major research universities.

Aycinena: Do you feel that 4 years in graduate school was enough? To address your experience at Berkeley and generalize, do think that's enough time to become a living expert on something. And as a graduate student, is 5 years better? 6 years? Is there a magic number?

Hu: There's no magic number. In my opinion, I think it is enough. In some other countries, students don't even spend significant amount of time on campus. They study on their own under the tutelage of some professors. And what education does is really give us a start. We're not supposed to be using just the knowledge we gained in university in our life. We're only there to learn how to learn. And it doesn't take that long to learn how to learn. What I think university does is to have a chunk of time where the students are motivated and not distracted by other things and study things, or at least get a start to study subjects, that are difficult and sometimes dry. And once you get started on chemistry-- even chemistry for me-- on physics, on biology, and communication and math and semiconductors, you are ready to go out and continue lifelong study. I think that's the right model of education.

Aycinena: One last question about the theory of education. For a typical graduate student-- and there is no such thing, but let's presume there is, and let's specifically talk about electrical engineering, computer science-- what's the equation, the proper balance of coursework versus research? What do you think?

Hu: Course work is important, I already mentioned, because this is the time in your life you could be forced to, or you can force yourself more easily than other times in your life to, get started on learning things. So that's important. Research is also important. Now time ratio. I really don't know how to answer the question. Typically universities now would require you to have-- let's say, 10 courses-- in the area close to your major, and I think that will be sufficient.

Aycinena: Does Berkeley require a minor for someone who's doing a Ph.D. In EECS?

Hu: Indeed. It requires actually 2 minors, one minor has to be outside the EECS. One minor can be inside the EECS, because EECS itself is such a large discipline.

Aycinena: Sure. It's a very complicated issue for undergraduates in electrical engineering, particularly their course work is so rigorous and so comprehensive, there's very little time for things even outside of EE. How does Berkeley, which is obviously where you spent the bulk of your career, how does the university address that issue?

Hu: It's a difficult issue. As professors, we are somewhat at odds with the students, and for understandable reasons. We advised student to try not to become a specialist in undergraduate school. This is the time when one should be exposed to a variety of things to be prepared for all the opportunities that may come along later in life. But students tend to want to become specialized in some area, because they feel that's an insurance for getting the first job. And so it's a balancing act. And it's not easy.

It's somewhat easier for us to convince the students who intend on going to graduate school. But even there, on the student side, there's always the concern that in the graduate school admission process, we penalize them if they cannot say, “I've done this I've done that”. And I always try to reassure them that, as a professor who reviews graduate applications, I wouldn't penalize students for not being a specialist. In fact, I would like my students to know a lot of different things. I often use my own example, of not being a semiconductor guy in my Ph.D. days.

And it actually shows also in my choice of research topic. I think it's good to have a variety of backgrounds and understandings.

Aycinena: I would love to talk for another two hours about things related to academia, how we get undergraduates to be more generalized when there's so much expectation and coursework. You can't even get through your freshman year without physics and chemistry calculus. And that's just the start of it. There's no time for anything else if you're really going to do an EE degree. But I want to go on with your personal story. When you went to MIT, and you walked in the first day to teach, was it very terrifying? Or are you a superhuman and that wouldn't feel intimidating to you?

Hu: I do not remember that as intimidating. I had looked forward to that. And as you know, most universities do prepare the students for teaching, when they are students, by asking them to do some TA and helping the professors doing things. So it was not a particularly intimidating experience.

Aycinena: What course work were you TAing at Berkeley? What courses did you TA?

Hu: At Berkeley, the course I helped out with was in the semiconductor area. And this is the time when Berkeley actually had not started to require mandatory TA. I was, I guess, fortunate enough to get free money and not to earn the TA money, But nonetheless, I remember helping my professors, preparing homeworks and grading homeworks. And I believe I did get extra pay for grading homeworks.

Aycinena: Think of it as hazardous duty pay, perhaps. So that would be an indication to me that even as a graduate student, you had perhaps an interest in teaching over industry. Although, as you say, you had these two wonderful opportunities.

Hu: I really cannot say I did. Although thinking back, I think there are many things that really prepared me to enjoy teaching later on. I think I am a person that would like to be able to explain everything in my own words. And I think that was very helpful.

I think, in retrospect, that I have a lot of empathy for students. I always think about the students, the frustration they must be going through. So it turns out to be a good fit for me.

Aycinena: Excellent. So 3 years at MIT, and I think you have told me you taught semiconductor electronics. More than one course? In more than one area?

Hu: Basically, it's this one course, 601, and I enjoyed doing that again and again.

Aycinena: And at that time at MIT had 6 areas, numbered 1 to 7, which is what they have currently? Rather infamously. So you were there in Boston enjoying the very hot summers and very cold winters. What made you decide to come back to Berkeley? Above and beyond the weather.

Hu: The weather was a consideration, given that Margaret and I never saw snow before we came to this country. And at that time, the chairman at EECS was Don Everhart, who later became chancellor of University of Illinois Urbana-Champaign and then the president of Caltech. He was the chairman of EECS. And he heard I started solar cell work at MIT, and that was the time that some people call the first US energy crisis. Berkeley wanted to build up a program on energy science. So he asked me if I would be willing to come and do that. And I jumped at that opportunity.

Aycinena: Is there a complicated loyalty issue, to let Berkeley lure you away when you were obviously becoming ensconced in the endless hallway, or whatever they call that at MIT?

Hu: No, I think there was a very long line of talents waiting to fill my vacancy.

Aycinena: Excellent, of course. Wonderful. So you came back out to California. Was there anything about Cambridge that you missed?

Hu: When we were there, Margaret and I enjoyed the New England countryside very much. It's a new experience, and that theme has come up again and again. Later in my life, I find out that having a new experience is very memorable, and very enjoyable. You just cannot be stuck in doing one thing in one place for very long. You want to try different things.

Aycinena: So you came back to California. And did it feel like coming home, to come back to Berkeley? Or had things changed at Berkeley, you didn't recognize it?

Hu: No, not much changed. I think there was a new Xerox machine. Now, I remember as a student when I was helping with the homework solutions, I had to use hand-cranked mimeograph machine to get the copies out to the students.

Aycinena: A word from the last century.

Hu: That's right. And so it was a very good homecoming. Berkeley, I think it's not a secret, has always had a reputation, at least, in the electrical engineering and computer science department-- as a very collegial department. For example, no professor owns a piece of equipment, even if his or her research grant paid for it 100%. Everything is shared. And younger professors get lot of nurturing, and I enjoyed that.

Aycinena: Are graduate students allowed to call professors by their first name at Berkeley?

Hu: They're allowed, but I guess it depends on the age of the professors. Not everyone was called by their first name.

Aycinena: And was anyone ever called by their first name at MIT?

Hu: I don't remember.

Aycinena: I'm trying to find distinguishing characteristics that might not actually be there. So when you came back to Cal, was it your intention to work in the solar area? And did you? And what was the extent of your involvement there?

Hu: It was my intention. I did. I actually expanded beyond the solar cell area because I wanted to build a program for energy conservation, energy management. So I started a new course called power electronics, talking about electronic devices and circuits to use for power management. And I took on another project, that is, the development of a gas-electric hybrid cars.

Aycinena: Very interesting. Very ahead of your time. And did you find that there was enough funding for your graduate students in that time for these very novel technologies?

Hu: Well, I did not have high expectations and could operate on a shoestring. I remember the first conference I attended as a Berkeley professor, I had to go to a more senior professor and say, can you support me to go to this conference? And I was supported. And so it was not an easy area to get funding for. For a new professor, this is always the case. But we made it work.

And in fact, funding became better later on. Until there was a sudden change. And the sudden change was that the new President, Ronald Reagan, decided that the government should not choose the winners and losers in energy technologies. And as he promised as part of this campaign platform, he turned the Department of Energy away from supporting renewable energy research. And so the spigot got totally shut off.

Aycinena: In talking to Lip Bu Tan, currently the CEO at Cadence-- I know he's a colleague and a friend of yours-- he told me that with the Three Mile Island crisis his career in nuclear energy was abbreviated, and he turned and went into other technologies. So it is amazing how politics, decisions at a bureaucratic level, or singular accidents like Three Mile Island can have these impacts on people's careers. So you were obviously impacted by decisions made at the Department of Energy, and what was your response? And professionally?

Hu: I did decide to change. And I was very glad that we already had some good results. The hybrid car was built, was actually quite widely reported, even in the newspapers. And I was able to finish a textbook on solar cells for terrestrial application with one of my colleagues, Richard White. But I had to look for other areas to keep my research going.

So this is where a helpful senior professor came in. Don Pederson. He was the chair at that time. And he told me that his friend Pierre Lamond, senior VP at National Semiconductor, was asking him for recommendation for a professor to do some consulting work.

And it turns out that work that Don recommended me to do for National Semiconductor was about non-volatile memory. Now this is what today we would call the flash memory. At the time EPROM was the mainstream technology. And National was developing E-squared, and Intel was another company that was doing it at the same time. That was my introduction to microelectronics and started my interaction with industry that changed my career.

Aycinena: How would you interweave the topics of solar energy and those material science and engineering issues with the issues about NVM? How would you compare and contrast those two technology conversations? Completely unrelated? There's an overlap? And if it is, where is the overlap?

Hu: You know, I was saying earlier, a lot of the basic knowledge is usable for many, many different applications. Solar cells, you need to understand the semiconductor. And for power electronics, you want to understand circuits. In microelectronics, it's also about the semiconductor, and it's about the circuits. I could certainly relate to that very quickly. And learning new things comes quite naturally for me. So very quickly, I was able to not only have a lot of fun, but also, I think,make a bit of contributions.

One of the things that I published was a a mathematical model for understanding how the EPROM was programmed with hot electrons, how the electrons get that energy, and how that process relates to transistor channel length and voltage on the drain, on the gate, and the doping concentration.

Aycinena: It was a good segue for your previous research into this area. So how was your involvement at National? Were you coming to the facility, the campus? Was it the one down here in Silicon Valley?

Were you coming daily? Not at all? Personally, was all your work on campus at Cal? How did you interface with National?

Hu: I came to the campus on Kiefer Rd, where it is today. Once every two weeks. And during the morning, I interact with the engineers, talk and understand what the problem is. Often in the afternoon, I'll work out some ideas and even finish my report for this particular topic.

Aycinena: Interesting. And how long were you involved?

Hu: So the consulting went on for all probably 1 or even 2 years. And then came the time I can do my first sabbatical. That was a time most professors would elect to go to Munich to have some fun with the family. I thought the industry topics are just so fascinating. So I elected to take the industrial leave rather than a sabbatical.

Aycinena: So if memory serves, from my own personal history, every seven years, professors at Cal were given a sabbatical. I'm not sure that that structure still exists. Had you been at Berkeley for seven years when you took your sabbatical?

Hu: It's close to, if it's not exactly that. But I replaced my sabbatical, gave it up, and ask the department give me an industrial leave. Meaning that I did not get paid by the university, and National Semiconductor paid me for that year. But my wife was not happy because we had just moved, and we moved to about 10 miles north of Berkeley. And she was unhappy that I would take a job so far away down south.

Aycinena: Were you commuting every day?

Hu: Yes.

Aycinena: I see. Contributing to the national glut, the national crisis on gasoline.

Hu: But I volunteered to carpool with a colleague, who actually did not have a car. I think I was redeemed.

Aycinena: So that year didn't sway you into staying in industry. You missed academia, and you still wanted to return to academia.

Hu: In that case, I never even considered to stay. And there was absolutely no misunderstanding or even expectation on National's part. But everyone is very happy because I could be just as helpful as a consultant. Because it's not about time. It's about ideas.

Aycinena: There's always a problem for me in research to have research on a time frame. Because who knows when the ideas will come? It's hard to schedule those things. So we know that we're talking about industry-- and I want to circle back to your academic interests in a moment-- but let's just talk about your industrial involvement. I have the list here. It's BTA, and Celestry, and Cadence, and ProPlus, and SanDisk, which are all extraordinary companies to be involved with. And of course, ultimately TSMC. But tell me how your involvement with industry evolved from National. Obviously you've come back to Berkeley. How are your subsequent involvements with industry? How did they fall out? And how did they occur?

Hu: The involvement in industry. First I should talk a little bit about the university policy on professors serving as consultants to industry. The rules initially were not very clear. And not many professors do consulting but as that becomes more commonplace the rules have clarified and, in fact, become almost a uniform university rule for the entire country. And that, I believe, is becoming a model for the rest of the world.

Aycinena: Do you think that model had its roots at Berkeley?

Hu: I would not say that. I would say it's something that the universities basically consult each other and gradually just converged into this one. That is, a professor can consult one day a week. And at least in Berkeley, it was further clarified. It doesn't mean to you can also consult on Saturdays and Sundays. So every year you can at most consult 51 days. And so this is the general rule.

Aycinena: And a philosophical question, if you're working on project X in the company, and that is proprietary by the university-- particularly public universities, like Berkeley, have an obligation to keep open transparency of research and use for public domain-- how do you marry those two problems? You've got proprietary work over here and you've got public domain worked here. How does that happen?

Hu: That's right. It actually works out quite well overall. Of course, this does take some discipline on the part of the professors -- maybe even the companies. But by and large, it seems to have worked out quite well. I'll use my case as example.

I try to take advantage of the knowledge I learned from the consulting work and bring it to the university in teaching, and in research, and in publication. You definitely cannot publish about those things on nonvolatile memory other than what National approves. But there was a new problem with MOS transistor for logic application, as it was scaled down to 1 micron. In the early '80s IBM had a series of well-known papers talking about sub-micron transistors. When it shrank the gate channel length below 1 micron, the high electric field caused the transistor performance to drift with time. I realized that what happened actually is the same thing that's happening in the EPROM. Except here, the energetic electrons are doing something that you don't want them to do. Instead of jumping into a floating gate as a memory program mechanism, now they are getting trapped in a dielectric that causes the transistors to drift.

So we started, I think, the first university research project on transistor ”hot electron” instability. The very thin oxide work went through a similar transition. I got a start through the consulting on EEPROM development. 100 angstrom oxide was used for electron tunneling erase of the EEPROM. Whereas the logic transistor was still using 400 angstrom oxide, I imagined the reliability problems that the logic transistor would have when its gate oxide is thinned down several folds.

And people already were worried with that reliability problem, not understanding that the failure mechanism. So I decided, that if we look at the 100 angstrom oxide, the picture is exaggerated and we can get the data faster and, based on that, we built a oxide reliability model and tested it on thicker oxide. It worked very well.

Aycinena: And those models are useful across all companies?

Hu: That's exactly right.

Aycinena: And you are coming to these conclusions by bringing things you're learning in the industrial setting and combining things you know the academic setting plus your own natural inclination to be curious about the larger discussion here. It seems to me that the proprietary nature of industry would be counterproductive to this process you just described. So how do we go forward with that when so many fascinating developments are happening inside of the firewall, the corporate firewall? How do we keep that conversation happening? How do we keep that process happening?

Hu: You know, I cannot say for all situations. But based on what I have observed, and certainly in my personal experience, that has not been very difficult. The companies typically are concerned about certain core things, things that are close to their product. Now professors shouldn't even be teaching those things and doing research on this on campus. And they'll teach the students more basic things, things that have general and wide application. I think companies can understand that. We mush distinguish between proprietary information and general knowledge.

However, it is true that the professors' general knowledge get enhanced by consulting for companies. And a professor then can and should make use of that enhanced general knowledge.

Aycinena: Well, you're seeing specific instantiations of something you at the university are looking at the general version, and this, as I say, is a specific instantiation within the firewall, which I call it. But I still think it's a very complicated process to do that and not violate company policy, patent issues, or to shut down the requirement for transparency in a public university.

Hu: It would take discipline, as I mentioned earlier. And some creativity on the part of the professor. Integrity, yes that's what I meant by discipline. Indeed you have to look deep enough so that you avoid the surface layer, or maybe even the second layer where it's questionable. But go deep enough and you will find a safe ground. And this is where you--

Aycinena: I think that's a good word, safe ground. Let's talk about BSIM. Give us the brief background, your involvement, and how you feel that has propagated throughout the world and impacted the history of humankind. I don't want to overstate but let's do it.

Hu: I don't mind you overstate. This is where, again, the larger environment has an impact on individuals' path. This is in the early '80s. I was still relatively junior on Berkeley campus. And Don Pederson, suggests to me that the accuracy of IC simulation is poor not because of the SPICE simulator architecture, it is because of the inaccuracy of the transistor model. He says, "you are a device physicist. Can you build a better SPICE model?" I found that SPICE model really was built on fairly simple or simplistic device physics. The kind of thing that we would teach undergraduate student even then. That actually worked quite well in the early years. But as transistors get smaller, going to sub-micron , things become more subtle, such that even professors don't understand what's going on. And there was no textbook about what really is happening. I think that's what Don Pederson saw that I could contribute. And that's the beginning of it.

Aycinena: So who was your group who was working on that? And I presume that Pederson and company gave you a lot of support for that.

Hu: Pederson--

Aycinena: Were you in competition with other groups within the department?

Hu: There was no competition in the department. And Don was really, I guess, a senior statesman, even then. So he actually gave me one of his student. He says, the student could work with you on this topic. So I started working with Bing Sheu. And the next year we hired a new professor, another Berkeley alumnus, into our faculty. His name is Ping Ko. So I invited Ping into this project. So there were three of us develop the first BSIM. We called that BSIM1.

Aycinena: For the viewing audience, tell us what the acronym stands for?

Hu: Right. So when the time came for publication, this student asked me, what should we call it? I had a choice. We could call this Movel level x, because the past SPICE models were called level one, level two, etc. But I thought, no, we should make a break. We're going to do this somewhat differently. And I said, how about calling this BSIM? Now BSIM is actually a tribute to another acronym, CSIM, which came out of Bell Labs. CSIM is a compact model, or SPICE model, developed at Bell Labs. And C stands for compact. Of course, you could think of SIM as standing for simulation, but the Bell Labs researchers actually find some words to fit SIM: Short-channel IGFET. And IGFET is an old name for MOSFET. So I said, well, let's change the C to B, for Berkeley. So Berkeley short-channel IGFET model, BSIM.

Aycinena: Did you ever get push-back from Bell Labs? If they thought that was a little too close for comfort?

Hu: I think the colleagues of Bell Labs were tickled pink. That we would pay tribute to them like that.

Aycinena: So what year would you say that BSIM became public knowledge and became the rage?

Hu: Of course, as university research we just publish as soon as we have it. And in the case of the useful compact model, probably release it to the users, to the SPICE users, before even journal publication. So everything is published in real time. Publish and release. The first release of BSIM-1 happened in 1984, as I recall. And then in '89 another student did BSIM-2. I guess four years later, another student, Jianhui Huang did BSIM-3. Now BSIM-3 is probably the correct answer to your question of when BSIM really become known. Now we're now talking about the '90s , I think 1994.

By that time, we have really-- and particularly BSIM-3 compared to BSIM-2-- added a lot of good original transistor physics into the model. During the 10 years we had been doing this, we accumulated a large body of very good device physics models. They were not developed totally under the banner of a Compact model. Because a Compact model user, quite frankly, don't even care about the physics, they just want the IC chip to work as circuit simulation predicts. It was done under the banner of device physics research. What is the real mechanism that determines the transistor IV curves? Well, what's this small leakage current? What's the mechanism of Vt roll off? And what's the real cause of noise in the MOS semiconductor?

So we answered those questions one by one. Like we discovered this leakage mechanism called-- I gave it the name-- GIDL. Gate-induced drain leakage. Lot of other people had just dismissed it as measurement error. But we look at that, and figure out that tunneling is causing it and that it will get a lot worse as the transistor becomes smaller. By the way, tunneling, I hope I'll have a chance to elaborate on this later on-- can be a useful thing. But today, as then, it is a very bad thing, a leakage mechanism. And noise is another example. We developed a model that resolved the conflict about whether MOS transistor noise is due to the fluctuation of mobility or the fluctuation of the number of carriers in the channel. There was a lot of debate about this in the literature.

Aycinena: We know from a conversation earlier, we have basic sciences versus engineering. I hear those questions as being physics-- device physics-- issues and not engineering issues. Particularly not electrical engineering issues.

Hu: Let me first finish answering your question about BSIM becoming known. Because of those new physics-based models, BSIM-3 became known.

You are very astute. In fact, even the choice of using the term “device physics”, I think, says something about an inferiority complex some engineers have or had. I really believe it's no longer there. But when I was a new professor, I believe there was that inferiority complex. Not necessarily that we feel that ourselves, but I think we think that the society view physics as being more intellectually challenging than engineering. And engineering professors might choose the words “device physics” rather than “device engineering” when they write a research proposal or publication. But really, I think engineering is a more apt word to describe what the engineering professors do.

And yes, we use physics ideas like tunneling to figure out what's going on and create engineering understanding, engineering model. Even more importantly, finding out what these models are good for. How can they make things better?

Aycinena: So let's take it back to BSIM-3, and tell us a little bit about the history of how that exploded on the world. And this ramping up of acceptance.

Hu: So the benefit of having these more accurate device physics, device engineering, models is that BSIM-3 was significantly more accurate than all the other transistor models for IC simulation, greatly surpassing even BSIM-1, 2. Also before BSIM-3, there was heavy reliance on curve fitting. Curve fitting of the equations based on simple physical concept or empirical equations based on the shape of the measured characteristics. But once we go deeper, we are able to derive predictive equations. For example, in BSIM-3, when we change the oxide thickness, not only the gate oxide capacitor changes, mobility will change, and the short-channel effect will also change. Because BSIM-3 captures the expected mechanism and how they relate to or depend on oxide thickness. The accuracy was so good that the industry very quickly converged to BSIM-3.

SEMATECH, probably at the urging of its members, then started to hold workshops on why the industry should have a standard model. I think they probably had BSIM-3 in mind, but they made it an open competition. And a standardization organization was formed. It's called the Compact Model Council, CMC, which continues to be active today. And they openly solicited candidates and several models were proposed.

Aycinena: This wasn't a rigged competition, was it?

Hu: There was some real competition eventually coming down to BSIM-3 and a model that Phillips contributed. Finally BSIM-3 was chosen as the first industry standard model.

Aycinena: To be very specific, what would you describe as the major differences as you went from BSIM-2 to BSIM-3? What would you say it was?

Hu: If I just pick one thing, I think it made the model much more satisfactory for analog circuit designers. For digital circuit design, people can tolerate a lot of things. Analog designers are very picky, and their product critically depends on having very accurate knowledge of the behaviors of the transistor.

Aycinena: Did you break open the champagne in the department when you heard that SEMATECH had chosen the BSIM-3 model?

Hu: You know, the BSIM-3 was, perhaps surprisingly, a little known project even in the department. I guess partly because I'm a low-key person and Ping Ko not much better. I'm sure we congratulated all the students, but I don't think we even mentioned that to our colleagues. I don't think they would hear about it until years later.

Aycinena: That's all right. If you eventually get the fame-- maybe not fortune but the fame-- then all is fair. So OK, we are now in the '90s. BSIM-3 has become validated by a larger world. What next? What came next?

Hu: '96 was when it was selected as the first standard model. Now that's a watershed. Once its the standard model, engineers and managers in all the companies feel safe to say, “Well, let's stop doing what we have been doing for years, it's crazy. Let's just use the standard model.” Dennis Buss, TI Chief Scientist, was a big booster for BSIM. He liked to tell people that all TI's financial contribution to SRC could justified by the savings BSIM produced for TI alone. BSIM made life easier and reduced the costs for companies.

Aycinena: I just want to ask a side question, and we'll go back to this flow here. It's very difficult for industry to embrace innovation not because they don't want to, but because they have legacy products to support and they have employees who inadvertently push back and say, please don't ask me to learn yet another language, another technology, another tool flow, whatever it is. So I think it's always very impressive when an industry leader does embrace an innovative change, but it does come at a cost. Much more so for our industry organization than for universities.

Hu: I appreciate that. So I have to say, even I was surprised of the speed at which this happened. Of course, the foundries, no-brainer, they actually adopted BSIM even before it became the standard. On the other hand, foundry was not as big a force in the industry as it is today. So it really was an overnight success. It just took ten years for that morning to arrive.

But there was another thing that happened , before BSIM-3 became standardized. I realized that quality was important. University software research usually has this problem. We love to do research, we want to do creative things. When it comes to documentation and make sure that it converges, it doesn't have underflow, overflow and gliches, we don't want to do it. We always think, well, industry will take it over and do it. And industry does not want to do it. This was a lesson that, by that time, I had learned. So I made sure that we made BSIM-3 version3 production-worthy and entered that in the standard competition.

Aycinena: So there were-- my impression of you have multiple streams of history going into the '90s. You have this ramping up and this, as you say, overnight success of the BSIM-3 model. You also have your work, which is going to culminate with a lot of research on the FinFET. And you also have your own academic career, nothing to do with your specific research but your increasing sophistication as a professor and your teaching skills. And somehow you're having to balance all those things simultaneously. Was it challenging? Was there ever time for sleep? Were you ever home?

Hu: I really did not feel challenged. I was, I guess, quite fortunate that I did not travel very much. I give first priority to classroom teaching. So I wouldn't miss my classes, I would just send my students to present papers around the world at research conferences.

Aycinena: I would not say that was the majority behavior among professors. They like the attribution, they like the fame of being at the conferences. I think that speaks well to you as a professor.

Hu: I like that too. But I think I was able to make that choice easily. And I'm very happy that I was able to spend time with my family as well. But I did put in long days. I know that then, and even now, I often-- well, I shouldn't say then because I didn’t use email as much. But as soon as we start using email extensively, which is in the late '80s, that was the ARPANET time. I often-- would write emails and not send immediately. But rather save them and send the next day, because I don't want people to know how late I stay up.

Aycinena: Nowadays, that's a badge of honor. In those days, perhaps not so much. So let's talk about FinFET. Let's talk, as I said, we're going to take just a step back here. And I want you to give me a quick lecture on the construction of a planar transistor. And from that, let's talk about the FinFET, how you became involved, what the DARPA funding was, and what the motivation was. So a lot in one question, but let's start simple but the planar transistor.

Hu: All right. I'm going to describe the planar transistor. I'll have use the analogy of a water hose. Transistor has a problem of power consumption. There are reputable company papers that have pointed out that if you plot the trend of what happened in the early '90s, semiconductor chips will dissipate more heat per unit area than a nuclear power plant core around 2010. And the surface of the sun in another decade.

So that is the problem that the planar transistor was facing at the beginning of the 21st century. Namely it appears that the leakage current just could not be stopped in a very small transistor. In a way it's not too difficult to see why intuitively. When you put any two electrical terminals very very close, if it's close enough, how can you stop current from flowing? That basically is the problem. We can think of that current flow as the water flow in a garden hose. Imagine you have a garden hose on the back lawn. Turning it on is not a problem. Similarly, a very short-channel transistor is great at conducting current, but when you want to stop it from conducting current, we we have a problem.

Imagine you have a long garden hose, right? You can stop the water flow by maybe stepping on it, or pushing on it with both of your hands. But what if this piece of garden hose becomes shorter and shorter? You can only apply a small force with your litt finger on it. It's getting harder and harder to pinch the hose to stop the flow. What do you do?

Classically, it was treated by making the MOS transistor gate oxide thinner. Many people, myself included, had learned in school that we would be able to scale the MOS transistors smaller and smaller, putting the source drain closer and closer to each other, if we made oxide thinner and thinner. However, I had been studying the reliability of very thin oxide and,. I came to the conclusion that thin oxide helps but is not sufficient.

Now, go back to the garden hose example. Reducing the oxide thickness would be like making the hose material thinner. That helps. But I realized that's not sufficient. You need to stop the soft lawn from sinking under the tiny force that you can apply. Ideally, the very short hose is flat and very thin and small and you can pinch it with two fingers from both sides of the hose. In transistor terms, we should build the transistor in a very thin semiconductor film and put thin oxide and gate on both sides of the thin film to control the current channel. But a silicon wafer is not a thin film. So I make thin fins stand on the wafer surface with the standard IC fab lithography and etch techniques. They look like the back fins of sharks. That's exactly the physical shape of a FinFET. It's a thin piece of silicon standing on its thin end with gate on all sides.

Aycinena: And did you come to that conclusion by thinking about the garden hose? Or did you come up with the garden house analogy after the fact?

Hu: Much after. After the media reporters started asking me what FinFET is.

Aycinena: So at what point in the day or night did you come up with this concept?

Hu: It's actually developed over a period of time. Although if you say whether there's a memorable moment, I suppose I could say the moment was meeting the deadline for a DARPA proposal. DARPA, in 1996, sent out a request for proposal. I remember vividly the title of the proposal is 25 Nanometer Switches. At that time very thoughtful experts in the semiconductor industry would say that MOSFET cannot be scaled beyond 100 nanometer. In fact, it's not even called 100 nanometer, it's called 0.1 micron. And that's why DARPA felt that 25 nanometer is revolutionary enough for it to get involved, to see who can come up with something.

Now, the fact that the call for proposals did not use the word transistor, to me, was also quite interesting. Switches. I believe they had in mind proposals like atomic, magnetic or optical switch or some other thing.

Aycinena: Have you ever confirmed that? That that might have been what they were looking for? Better not to.

Hu: I did not ask. I would imagine that's what they have in mind. Because there were many publications about those. And by that time, I had been thinking about this for a while and already figured out what you have to do. That is no longer relying on scaling the oxide thickness but rather scaling the body thickness. I remember flying to Tokyo for a conference, and there was no iPad or even any good portable computer. So I used free hand drawing and writing to write the technical portion of the proposal.

Aycinena: Paper and pen.

Hu: On paper. When I got to the hotel. I faxed the technical part of proposal to my colleagues at Berkeley and ask them to put the other parts of the proposal together and send to DARPA. I wrote down 2 proposed structures all based on this one concept, that is, thin body. And the first one we proposed is FinFET. For this structure, you don't need new nanometer thick thin film material technology. But rather you start with a regular silicon wafer and etch these thin fish fins. So that's the FinFET.

Aycinena: First of all, very simple question. Who and when did you come up with the fin? When did it look to someone like a fish? A hotel room in Tokyo? At what point?

Hu: It came after the proposal was accepted, in the program review. And many companies were invited and all universities' researchers invited. This is the way the research sponsors do the review, which actually promotes a lot of cross-fertilization of ideas and give industry opportunity to give input to DARPA. And so it's in one of those locations, someone commented it looks like a fin.

Aycinena: Done. I have to ask you what the other proposal was, what was your other suggestion?

Hu: Right. It's in the same proposal that we said we're going to investigate two implementations. The other one anticipates a future day, when the SOI substrate manufacturers can make the silicon film, thin enough. We predicted, and later verified experimentally, that the silicon thickness must be reduced from 100 nanometers, standard at that time, 4 or 5 nanometers in order to make a 20 nanometer transistor. I give it the name, ultra-thin body, or UTB. So that's the second structure. You get a 5-nanometer SOI film, I'll give you a 20 nanometer MOSFET.

Aycinena: Let's circle back to that in a few minutes. But let's talk about the trajectory of the FinFET. Now that it's been given research blessings by DARPA, where did you take your research funding? And how to assemble a group? Was it a continuum of research for the group you already had? How did that work? I mean, we're talking about the late '90s here, right?

Hu: That's right. I think we got the money in '97. And so it was just a Berkeley group. We felt that we have all the skills to get this done. So besides myself there is Professor Tsu-Jae King, who is the department chair today, and Professor Jeff Bokor, who is associate dean at Berkeley today. And we have, I think, at the peak of the program about a dozen professors, students, visitors and a post-doc. The post-doc working on that project is now also a professor at Berkeley, Vivek Subramanian. That's the group that got it done.

Aycinena: I think people are always very excited to be working on something new rather than working out tedious details of implementing something that someone else has already come up with. I would imagine there was a lot of energy and excitement in the group.

Hu: There was. It did not have a lot of encouragement say, for example, from industry. They, I think, probably do realize it's a good idea. But the industry's attitude to all idea is , show me, until it's done. So while we are doing it, there wasn't much encouragement. Of course, once we showed the experimental result, the picture quickly changed. Nonetheless, there's a lot of self-generated enthusiasm and it's just fun to work with students. And not just on this project. Actually on every project it's really the students that sustain the work. Their energy. It's just so important, critical, to the success of every project.

Aycinena: How many years would you attribute to that project?

Hu: I think we got the money in '97. By December of '99, we were able to publish a very convincing FinFET result. At IEDM.

Aycinena: This is 2013. And I would say as a journalist, I started hearing background chatter, maybe 4 years ago. A little more chatter 3 years ago. And now it's the rage. Why has it taken 14 years for it to become the rage?

Hu: This is not too much a surprise to me. In 1999, December, we publish the results at IEDM. And it, did receive quite a bit of media--

Aycinena: Packed room at IEDM?

Hu: In early 2000, I remember a reporter asked me, "how long do you think it's going to take to get into production?" I said, about 10 years. So in 2011, Intel did it. It's not surprising it took that long. I did not understand the reason when I gave that answer as well as after I had my stint with TSMC. This industry—the semiconductor industry's amazing manufacturing technology has a secret ingredient, a little-known ingredient. I call it incrementalism. Don't make big changes. Don't make a big change when small changes will do. And don't make any change if that will do. And I have come to really appreciate that. That's the wise thing to do.

Aycinena: So I think incrementalism is an interesting term. Corollary conversation is evolution versus revolution. Clearly there's an industrial motivation. There's a certain inertia, as you say, an understandable inertia, that I think leads to evolution. Universities maybe are more free to pursue revolution. Somehow they have to meet. But, as you say, eventually the physics of this shrinking geometry is going to cause you to have to make a disruptive change.

Hu: This is a very good point. In the concept of evolution versus revolution, what is the academic researchers' role ? I think it's an important topic. Sometimes words make a difference, like scientists versus engineers. And now I think technologists seems to be a respected descriptor. And everyone on campus from different colleges all want to be known as a technologist, which I think is a good thing. This is a good thing for the world.

I think that same about evolution and revolution. Many people in semiconductor industry think FinFET is revolutionary. But actually, at the time I decided to go in this direction, it's actually evolutionary relative to those atomic switches that I think some others are working on. That, I think, is a skill, and maybe it's a discipline, that academic researchers need to nurture. Often things that are too revolutionary, although worthwhile and interesting, may not be the best way of spending the current asset. Because having that done later on is not going to hurt humankind at all. Although you may be deprived of the bragging rights to say, I wrote this paper.

And I learned that fairly early on. My Ph.D. research topic-- integrate optics, putting optical circuit in the thin film-- is just beginning to see wide application. Whereas by moving into the semiconductor field, I was able, I believe, to actually make more contributions with decades of my life.

Aycinena: Again philosophically, I hear you saying that students have to be both revolutionary and patient. And those are sometimes, not diametrically, but they're orthogonal. They're orthogonal, the patience and the revolutionary innovations. So complicated.

Hu: It really is. And I also think that this topic is complicated by the fact that the technology time scale is changing. People used to be willing to wait for technology to take 30 years from inception to production. Spend a whole lifetime on it, that's fine. But today, the world really wants new things to come in a lot faster. 10 years, 15 years, 20 years at most, and one has to have the wisdom of seeing realistically, is this going to happen in 20 years? Is it going to be much longer than that?

Aycinena: Silicon Valley is a complicated place. We simultaneously talk about yesterday, today, and tomorrow. And you really have to listen carefully as people talk through the time frame of what they're talking about. And I mean, figuratively yesterday, figuratively today. We speak in terms of tomorrow, we speak about in the present. It's very confusing. Part of it's the marketing message out of Silicon Valley, part of it is what you're talking about. How long it takes to implement technology and put it out into the hands of the consumer.

I'd like to talk about TSMC. I'd like to talk about your involvement there. And at the same time, if it's possible talk about the complexities of implementing, of incorporating FinFET into this global manufacturing infrastructure that we have, and how complicated, how disruptive a change that is. Should we take a break for a moment before we launch and all that? Or can we keep going? What would you like to do?

Hu: I'm OK.

Aycinena: Perfect. I'm fine too. So let's keep going. TSMC, in 1990, perhaps was not a household name. Today it is massive. It's definitely a household name. How did that happen? And when you were involved, how did that happen? And with the empathy and the knowledge you have about that manufacturing-- and not just TSMC, the manufacturing infrastructure-- as I say, how do we get them to make these incremental changes toward a whole new transistor structure? A lot, can you answer it all? And I'll remind you, if there's too many questions all at once-- So tell me, first, how you started at TSMC. Let's start with that.

Hu: My family moved from mainland China to Taiwan when I was a two-year-old. I got my education in Taiwan, and have wonderful memories of my life there. And while I build my career in the US, I've thought about doing something for Taiwan by going to Taiwan to work for a period of time. And when I thought about that, usually it's thinking about taking a sabbatical at university and all of that. I like what I do in Berkeley so much that I have never taken a sabbatical in a foreign country, or even another university. I did take this industrial leave at National Semiconductor, but all of my other sabbaticals, I actually just stayed on campus. Just take a break from teaching, and really get more research done and enjoy that.

But the year 2001 was an opportunity for me, because our younger son, Jason, would be a college freshmen. And even our older son, who has a special need, has an opportunity to get special learning in a residential program, which he wanted to do very much. And I thought, here's my opportunity to spend a year or 2 in Taiwan. And at the same time, I got an invitation from the president of a university in Taiwan saying, “would you like to consider taking the directorship of this Institute or another one or both of them at the same time?”

Aycinena: An embarrassment of riches.

Hu: I agreed to go and visit for a day. And a thought occurred to me. I knew TSMC, I have done some consulting for them. I had inkling that they would like me to spend some time there. So I made an appointment with Morris Chang, saying that I'll be in Taiwan that day, could I come to visit you? So he said, Yeah, please do. When I saw Morris, I told him that I'm here because I'm thinking about spending 1 or 2 years in Taiwan-- and do you think TSMC would like me to do that? And within two hours, Morris got all the executives into this and everything was set. They created the CTO position for me. So I was the first TSMC-CTO.

Aycinena: --probably knew how to reach HR on this phone, I would imagine.

Hu: So I promised to be there for 2 years.

Aycinena: It must have been a very exciting time. But also, 2 years is a long time to be away from home. And did your wife look forward to that?

Hu: Unfortunately for the family, it turned out to be longer than 2 years, eventually.

Aycinena: In what part of 2001 did you arrive permanently in Taiwan? And how long did you end up staying?

Hu: June. Yes, after school ended.

Aycinena: And you were there 3 years?

Hu: That's right.

Aycinena: And were your sons able to come and visit you on occasion?

Hu: Yes, they were.

Aycinena: Did you get home leave?

Hu: They did come on vacation, and I did get home leave. And my wife is the one that accumulated more frequent flyer miles than anyone else.

Aycinena: How was your Cantonese at this point?

Hu: Margaret says my Cantonese started going downhill after she said yes to me.

Aycinena: Don't feel bad. My husband says his Spanish has not been good since he married me. I speak better than he does, now at this point. It's widely known. So there you are living in Taiwan and not knowing how long, thinking it's two years, and can you describe in not proprietary terms what the nature of your work was? I believe Dr. Cheng made a new position for you, created a position for you specifically. How was that, to carve out this new role as CTO? And what were your involvements that you can tell us.

Hu: So he gave me quite a bit of leeway to define what we need to do. Of course, he also tells me what he thinks we need to do. One is to lengthen the R&D horizon of the company. TSMC was known to be a fast follower. And it has this amazing ability to do things very fast and very well. But because it does things faster, tends not to look far, it just do what has to be done. So that's my job, to really create a longer horizon of research.

Aycinena: Wasn’t that challenging? Were you going against an internal culture in the company that you were fighting against in order to create that longer term view?

Hu: Not really. TSMC is a successful company, I believe, because of the culture more than anything else. And one of the values is held very high there-- probably the second most important value there, really-- is everyone works for the company’s success. So there really is very little internal conflict.

Aycinena: What is the first value?

Hu: That is the service mentality. Namely, the company is a service company. And we're here for the customers.

Aycinena: How did you know at the end of two years that you were going to stay another year? Was that a very tough decision?

Hu: Second year wasn't so tough. After the second year, going to third year was not so tough either. That's still something quite different from permanent separation from the university. The Executive Vice Chancellor, Paul Gray, had told me when he approved my request for the third year of leave that there would be no more extension of my leave. So after the third year, deciding to come back to the university or to stay at TSMC was a lot tougher.

Aycinena: Were you involved with the university there while you were there, along with your obligations at TSMC? Or were they, you could do one or the other?

Hu: Basically none. I have always preferred to keep matters very simple. No divided loyalty. Similarly I had minimal involvement with Berkeley. And my colleagues were supportive. They help to take over my Ph.D. students. And those that are very close to graduation, I think, got some acceleration toward their graduation. So I think all were happy. The only thing I kept connected with, is the maintenance of BSIM. Because that is a commitment. I know that no one else can do it. So I would make a long telephone call each weekend to post-docs at Berkeley and keep them supported.

Aycinena: So it's a simplistic question, but during the 3 years you were at TSMC, was there a lot of conversation about this new transistor? Did you attempt to help them understand it needed to be on their road map at some point? Was that not part of your conversation while you were there?

Hu: It became one of the things that I started there. I started many things. This again, quite frankly, is on the far long side of TSMC time table. So that's not a major activity.

Aycinena: What process node were we at in year 2001? 2002?

Hu: It was getting ready for the 90 nanometer node. And the 130nm node was just ramping up.

Aycinena: And so there are all sorts of lithography issues, no matter how you transistor looks, that obviously crop up once we start to hit a certain wavelength of the lithography. So it sounds like you might have been around the time that those things were happening. If you're the CTO, how do you keep view, worldwide, of what everyone's doing to solve this problem.

Hu: You know, it's very good that you used lithography as the example to ask these questions. And that makes it easy for me to answer. TSMC does not have as broad, as deep a bench, perhaps, as Intel or IBM. After all, it is a younger company. Nonetheless, it does have great talents. And one of them is Burn Lin. Now Burn Lin had years of experience at IBM and, by the time I joined TSMC, he was in charge of the lithography program. And he is a VP at TSMC now. He had a reputation of being more optimistic about the future of optical lithography than most of his colleagues in the lithography community. The following story is something that TSMC can be very proud of. While I was there, the ITRS, International Technology Roadmap for semiconductors, the collective wisdom of all semiconductor companies, included four or five potential next generation lithography technologies like the 153 nanometer, E-beam something called SCALP, and the most prominent of all, EUV or extreme UV. It turns out that none of those on the ITRS list became the next generation technology. And what became the next generation technology was championed by Burn Lin for many years. His was almost a lone voice. And that's why it was not in the ITRS roadmap. That's the emersion optical lithography technology. TSMC, through Burn Lin, really believed in immersion. So TSMC was the company, when I was there, that worked with Nikon and ASML on the immersion optical technology, which emerged as the right choice.

Aycinena: Sometimes it seems that people have great foresight, and sometimes it seems they're just lucky. How would you describe this immersion decision to go with the immersion technology? Good luck? Good foresight?

Hu: I give luck a great deal of credit, in general, probably more than average persons. But in this case for Burn Lin and TSMC, I really believe that they are smart and confident. Burn Lin has publicly stated this case over ten year and with good analysis to back it up and TSMC put significant corporate resources to convince the lithography industry and get this new technology off the ground. So calling that luck is a stretch.

Aycinena: I was at a research symposium, IMEC, in Leuven, 2005. So there's the year, as a note, 2005. There was, at that point, a huge enthusiasm EUV. And that was going to be the future. And obviously, I'm not criticizing IMEC, would never do that. But I think it's not always clear--

Hu: You're absolutely right. Absolutely right. There was one proposition in front of us at TSMC a few years before 2005 to join the heavily financed industry EUV Consortium or risk being locked out of the technology. What do we do with EUV? You can imagine, it's a very weighty and difficult decision.

Aycinena: As a matter of fact, if memory serves, in 2005 I think IMEC also was announcing, at that point, a partnership. That TSMC was going to be one of their research partners. For the first time. And I'm sure that research has been interesting.

Hu: And of course, IMEC has a cost effective model of doing shared research.

Aycinena: Very complicated issues. And very technical issues. Very, very complicated. So just a personal question. Anybody outside of your work world ever understand what you do? Your family? Your friends? Is it even possible to explain to them?

Hu: My wife thinks I don't tell her enough about what I do. So I think if they don't understand, the fault is all mine. My son-- my younger son Jason-- studied bioengineering at Berkeley. And to my great surprise and pleasure, he enrolled in my semiconductor device class.

Aycinena: Well done. I certainly hope he didn't get any special favors in the grading.

Hu: Indeed not. After he finished his degree in bioengineering. He decided to enter Pratt Institute in Brooklyn. Which is an art institute. He wanted to study industrial design. And when time came for me to publish my last textbook-- by the way, it was published in 2010, and it was the first textbook that I know of that had FinFET coverage.

And Jason gave me a wonderful gift. He designed the book jacket and cover, for that book.

Aycinena: It doesn't get any better than that. So clearly he understands what you're doing, at least he claims to. So your involvement with the other companies I mention, BTA, Celestry, Cadence-- those come before or after, in and around the TSMC involvement.

Hu: Before.

Aycinena: The involvement as being on the board, or being the technical advisor.

Hu: So on the industry side--

Aycinena: In the '90s.

Hu: --industry involvement side, as I said, National really was the break for me. That one year at National, I think, so much more valuable than I could have had as a sabbatical professor at a university, because it's something new for me. Really broadened my horizon. My research into the hot carrier reliability, oxide reliability, and they became models that process development engineers, the technology developing engineering and manufacturing engineers use to do fast testing of the reliability of the device and those techniques continue to be used today.

But in the meantime, because of the BSIM work I have some interest in linking these reliability models to circuit design. So I started a project that eventually became the first reliability TCAD tool, reliability simulation. The idea is that this tool-- we'll call the SPICE simulation result-- get the voltage waveform at every terminal of every transistor. And based on that plus these reliability models, the simulator will predict how the transistor behavior or the SPICE model of each transistor, if you will-- the SPICE model parameters of each transistor will change, say, 3 years from now, or 5 years, or 10 years from now. And after that simulator re-simulate the circuit again to tell the designer how the circuit performance will look like 3 or 5 years from now. And we called that tool Bert. B-E-R-T. Because my kids were young , and BERT is a Sesame Street character, of course. This acronym stands for Berkeley Reliability Tool.

Aycinena: I'm sure Sesame Street doesn't realize what an inspiration they've been. Fabulous, that's fabulous. So the tool-- are we talking about a commercialization of the tool?

Hu: That's correct. So that leads to the answer to your question. So the tool was, of course, released following the Berkeley tradition, free for everyone to use and published, and got very good feedback. For example, it won the first SRC Outstanding Research Award because it was the first time for anyone to do something like that. And the companies all said, yeah it should be very useful, but no one used it. And this was the time, as I said earlier, I didn't understand that research software is useless. A company wants something that always converges, and there's someone to hold hands for the engineers so that they can be productive.

So after a few years, Ping Ko and I decided we'd just do a start up to commercialize BERT. And I got some high school friends who are well-to-do businessmen now to be the angels, and we started the BTA, which later, as a result of the merger with another company became Celestry.

Aycinena: Which I am familiar with, and what was the evolution of Celestry? What was their trajectory? Or history as we

Hu: Celestry was successful to commercialize this reliability simulation technology, and in 2012, it was acquired by Cadence. Celestry merging into Cadence was a very successful integration, very good for both the former employees of Celestry as well as Cadence. And this technology now has permeated to the other companies in the industry. EDA companies all have a similar product doing reliability simulation.

Aycinena: Do you have an opportunity to know how it's doing, the actual technology? How it's surviving or thriving within its current home?

Hu: The reliability tool is still a small part of the design flow, and its usage keeps improving because people do want to know whether their IC product is going to be out of spec after certain years. Other parts of the Celestry, which grew even bigger than the reliability simulator-- UltraSim was another product that Cadence acquired from Celestry. It's doing very well.

Aycinena: Those are very complicated business issues. I heard a talk, maybe three years ago, might be four, that the new chancellor at the Merced campus for the UC system, obviously the newest campus, and I believe his background was at Bell Labs-- when we edit this transcript I'll have to insert his name because I don't remember his name.

Hu: Steve Kong is his name.

Aycinena: Exactly, thank you. I remember him speaking very adamantly in this keynote I heard him give at a conference about the fact that engineering is important. I think he might have suggested it was more important than basic sciences. I don't want to attribute him inaccurately. The more important thing he had to say was that engineering ideas are nothing unless they're commercialized. And he meant it in the best term, the most robust meaning, that it actually has to be in the hands of the users and has to be stable, has to be supported. And without it, you cannot claim to have any engineering innovation at all. I'm probably overstating what he was saying, but I certainly took that away as his message. And I thought it was a very, very complex message. And it's reality.

Hu: I think it all has to do with the accelerated pace at which things are happening. Our industry colleagues just don't have the time to tie up the loose ends for academic research, and they want us to finish it. Or, at least, give them a very clear indication that all that's left are these very specific things that universities cannot do.

Aycinena: Sure. So we've talked about TSMC, and we talked about your work there. When you came back to Berkeley, was it such a change in pace for your day-to-day life that you missed the pressure of being in industry, the excitement of being in industry? And how did you transition back into academia?

Hu: Well I missed traveling in business class.

Aycinena: Excellent. Way too honest.

Hu: That's right. And for some reason, the university gave me a much smaller office than the one I used to have, but it still has the same room number in the same building:-) So those are the differences. But the excitement that one gets from working with the students is still there. And the students are just as eager, as smart as ever.

Aycinena: And in that timeframe, I spoke to you briefly about it at your celebration last December, Richard Newton-- for a brief moment-- was obviously head of the EECS and then very tragically passed away so quickly from his illness. Did you work with Richard in your early days? Did you interface with him when he was dean? When you came back he must have been dean at that point.

Hu: Indeed. And I have the good fortune of working with Richard when he was chairman and then as dean. And you talk about optimism, and he's certainly one of the most optimistic persons that I've known. To him, nothing is impossible. He is willing to bend rules to get things done. And he is just a remarkable person.

Aycinena: So his life and also-- not to compare and contrast-- but also speaking about someone like John Hennessy. These are people who have spent a lot of time in administration and also in teaching and also have a shadow-- the footprint that they've had in the technology contributions. I think that people who are evolved into being administrators in universities have less time for research and less time for teaching. And I think it's sometimes a loss, for them personally. So maybe you were doing less primary research at TSMC. Did you miss the opportunity to be in the lab? Whatever that means, when you were at TSMC?

Hu: Not really. I've always enjoyed change. Doing something different to me is always exciting, and I always enjoyed that. Of course, when faced with a choice of forever doing this versus forever doing that, I could have a real choice there. But doing something different for a period of time, I always enjoy that and still look forward to more of it.

Aycinena: It sounds like your diversity of experiences are always circling back and contributing to your technical innovations. Because a little bit of this, a little bit that, put it together, and the sum is bigger than-- the whole is bigger than the sum of the parts, which brings me to a topic about innovation. And I know there's been a lot of complaining in the last few years, personally I don't know why, about people being too specialized. I think that's not something that's just happened in the last few years. It's been true for a long, long, long time, decades, centuries, generations. You come to know a great deal about a very small topic. But I think innovation sometimes requires you to know a lot-- a little bit about many things. So again, I'm asking you for a quantization, an equation, a percentage. At what point do you know too much, too little about many things and not enough about one thing? So another way of phrasing that is, how do we get our graduate students to not be so specialized? Do we want them to be not so specialized? I mean, is this a concern?

Hu: I think we do. I think we do want them not to be too specialized. And also I don't want people to be superficial in their knowledge. So it's all about avoiding extremes. Confucius' teaching —strongly advises us to avoid extremes and be moderate. On this topic, we can learn from that. And that certainly has been my life philosophy.

Aycinena: My impression from hearing this story is that you did bring knowledge that you accumulated here, knowledge and nuanced knowledge, not just facts, but a nuanced understanding of these different paradigms, whether it's just industry and academia-- more complicated than that-- and bringing them together. And I think sometimes that's a magic. Maybe there is luck to that. It takes a certain intellect and hard work, but also having your eyes open all the time too.

Hu: So this is indeed how I think most professors advise their students. But it's hard for the students to really appreciate not to be too narrow and wait for later to become a specialist. While in school, take advantage of the fact that you could learn a lot of different things in a way that doesn't take too much of your effort. It's all there on the same campus. You can do it in the same day. So do that. Take advantage of that. But at some point, you should also put in the time and dig deep when you really want to make a big, new contribution, innovation. So you need a combination.

Aycinena: I hear you say balance. So 10 years ago when my daughter started her PhD at MIT, I took the opportunity when I was there to interview Shingree Davidis from MIT, and at that point he was lamenting the quality of the students coming into the universities, that they were inadequately prepared across-- and this is relevant to this topic of breadth versus specific-- they need more training in electrical engineering, more training in computer science, more training device physics. If he were here, I think he would respond to my comment. There's just so much to know before you can actually push the envelope. How can we make sure that our students know enough? What's the perfect curriculum? Who decides all that? How can we decide that?

Hu: Yeah. There is a trade off between breadth and depth. And what I was saying is that in terms of advising the students, their tendency seems to be wanting to have more depth than breadth, and so I always make an effort to balance that tendency by suggesting to them to not be too much in a hurry to develop depth, but take the opportunity-- to take advantage of the opportunity now, to build breadth.

Aycinena: So the philosophy aside, at what point did the New York Times, or similar kinds of lay press, start knocking on your door and asking about the FinFET? What year would you say? 2011, is that the year?

Hu: Actually the biggest flurry of interest was after the publication of our paper in 1999, to be frank with you. I don't know exactly why. For some reason, probably because when the reporters check their industry friends about research news, they were pointed to FinFET. So at that time, we actually say a big flurry of media interest. After the 2011 Intel announcement, of course, there was interest. The day after the New York Times article appeared, I started getting calls from IEEE, Spectrum, and all that. But not a huge number. I think the reason is that FinFET is no longer a little known thing. There are many experts. Many companies have had done research on that for years. So there's plenty of sources of information.

Aycinena: Very currently, two days ago, I interviewed the executive of a company out of the UK about FinFET. And I had published a blog a few weeks ago, saying FinFET-- yes, no, maybe. And his company contacted me and said, it's an absolute yes. And they wanted me to talk to him, so I did. And he was adamant that there's no maybe about it. It's absolutely a yes, and it's going to happen within the next year. He was very dramatic about it. But I said, what about the cost of retooling at the manufacturing level? He said, those costs are way overstated. 3% to 5% is what he was estimating. What would you consider to be the cost of retooling, not specifically TSMC, but for what I call the global manufacturing infrastructure?

Hu: The conversation you just described, when did that takes place? Did you say just a few weeks ago?

Aycinena: Day before yesterday.

Hu: Oh OK. Yeah, I think he's right. In fact, Mark Bohr said , maybe even in that very first New York Times article, that according to Intel's experiences only about 3% to 5% more costs, compared to planar technology in the same generation. And in addition, he said there's no special equipment needed, which is very significant information. And I totally agree with that. In fact, I was even thinking, perhaps, that the answer would be not even 1% higher for retooling.

Aycinena: But who is absorbing the change? Is it at the mask making? There has to be some change, or am I just looking for problems?

Hu: It's reasonable for you to think, how could one give us 3D structures that look complicated without paying something for it? And that problem was dealt with in the original vision. The aim that I set for myself when I was looking for ways to deal with this problem of how to solve the future scaling beyond 25 nanometer was two things. I said, one, we just have to reuse the manufacturing technology as much as possible. That's why we wanted to stay with the semiconductor technology and CMOS, if possible. Two, reuse the design infrastructure as much as possible. We don't want to adopt a transistor that has terminal, characteristics, I-V curves that looks very different than what we're used to.

Aycinena: Incrementalism.

Hu: That's exactly right. So those are the two things I had in mind. And with regard to the first, about manufacturing, I had actually considered many other ways to make a thin body. But when I got the FinFET structure in my mind, I felt, this is it. Because it really is very easy to make in an existing fab.

Now why is it easy to do? This is perhaps a little more of a technical answer than you asked for. Well let's try that. Assume you're making a conventional planar transistor. One of the first things an engineer does after he gets the wafer is actually to etch trenches and then fill the trenches with oxide, and then planarize the whole wafer. So that if you look at a cross section, you get an oxide trench on the left, you get an oxide trench on the right, and in between is a piece of silicon. Now this piece of silicon is where you make your planar transistor. So keep that picture in mind.

Now, I want you to imagine the following way of making a FinFET. How do you make a 3D fin? This is what you do-- the same two oxide trenches, but you just put them as close as the lithography allows you to. All right? You get a really very thin piece of silicon in between the oxide trenches. And now you etch the oxide a little bit. What this does is to exposes the silicon in between the two trenches, exposes the tip of that thin piece of silicon. That's the fin. After that, everything's the same as conventional planar transistor manufacturing.

Aycinena: Did you have that manufacturing in mind--

Hu: Absolutely. Yeah. So this is why the retooling is minimal.

Aycinena: So what you're telling me is that the problems associated, or the concerns, have been overinflated. That there really isn't-- so why is there any cost associated with it at all? Why is there even 3% to 5%?

Hu: That's what I'm saying. I was actually thinking it could be 0%. But it's possible that, especially with something so new, you want to be on the conservative side. Don't cut corners. Maybe I could have saved this or that. But let's not do it now. Let's see if next time we can save it.

Aycinena: So one more question. Everyone talks about the 14 nanometer FinFET. Why are we waiting until this process node to implement it? And which brings me to my other question, why didn't we do the transistor this way in the first place?

Hu: Well, the answer to the second question is incrementalism, right? It is harder to do it the way I described than doing the planar, especially if you think that the first place means the 1970's right? At that time people actually did not etch this trench for device isolation. People used different ways to make the planar transistors, a lower cost method rather than this shallow trench isolation method.

So FinFET, if you will, becomes very attractive, really only because we knew that shallow trench isolation was coming online soon. It wasn't yet the standard isolation process when I proposed to make the FinFET, but It was already clear in the research community that that's what is going to happen.

Aycinena: So you're saying that manufacturing processes were not in place and '60s and '70s--

Hu: That's correct.

Aycinena: That level of sophistication had been reached such that this could be envisioned.

Hu: But even in 1999 or 2002, things were not broken. You don't want to do FinFET until you decide, as Intel decided in 2011 that old way was broken. After Intel had done it, my guess is that TSMC asked themselves, why didn't we decide to do it sooner ? Could we have saved ourselves some trouble? The fact is that TSMC, of course, has a certain technology schedule. They promised their customer many years ago that the 20 nanometer would be there. Customers have started to design products for this 20 nanometer technology. But it's not a secret. TSMC is trying hard to push its FinFET to come out.
Aycinena: But it's the problem in industry. You have to support your customers. You have to be talking with them about the future. And yet deal with the present, so it's complicated.

Hu: The first adopter of a new technology really deserves a lot of respect. As you were saying, it's very hard for industry to use something new, or not use something old. It's actually very difficult.

Aycinena: If you're chip designer, does it matter to you how the transistor is assembled?

Hu: Thanks to EDA, the design automation tools, designers really shouldn't have to worry. It should be basically transparent to them. I mean that in a somewhat simplified way. But basically shouldn't.

Aycinena: I've been doing the work as a journalist in EDA for 15 years, and I have seen a very serious evolution from the engineers being completely free of all responsibility for the manufacturability of the yield of what they produce to being -- their feet are being held much more to the fire, for what they produce has to be manufacturable and has to have a pretty respectable yield.

Hu: So FinFET actually is somewhat of a relief for that. The reason the manufacturability becomes a necessary part of the designers' responsibility is because the process side already tried their hardest. They can only guarantee this much variation, and very unfortunately, that much variation causes the transistor characteristics to change in a large way. In other words, the transistor has become very sensitive to the gate length, CD, so-called.

Aycinena: Which isn't surprising at these dimensions, that there's such a sensitive response to even the slightest change.

Hu: Yeah, it is, of course, over the decades becoming more and more sensitive. But FinFET will be less sensitive to this gate lengths for the same generation. And so FinFET will, at least temporarily, give the designers some respite. It doesn't mean that the problem will not quickly escalate to a crisis level again.

Aycinena: So we had mentioned, and I'd like to go back just for a little broad conversation about tunneling, the good, bad, and the ugly of tunneling. It used to be a problem, how it's viewed today-- just give us some words about that.

Hu: Sure.

Remember we were talking a while earlier about one of the models that we introduced into BSIM. It's a new leakage current of the MOS transistor. We found there's a component of leakage current that couldn't be explained by the know sourcs of leakage. And we found out it has to do with the electron tunneling at the drain-channel edge that's created by the gate voltage. Once we discovered that and reported it, friends in the industry told me, “wow, you really solved a problem that has been bothering us in the DRAM industry”. Turns out DRAM refresh time was limited by that. That leakage means the charge cannot be held on the DRAM cell capacitor because it leaks through this transistor drain. Once we explained the cause of this leakage, it became easy for engineers to figure outthat by adjusting the profile of the drain doping, making it more lightly doped near the drain edge,you can eliminate that leakage. So that's what they did.

So now fast forward to a few years ago. This is after I returned to UC Berkeley from TSMC. I was a new professor again, having to find research funding and start a new project. And of course, it was a little different than when I was the new professor for the first time years ago. That is, I was more careful in thinking what I wanted to do. So I decided, I don't want to do something that's easy, and I want to do something that's really hard, that may not succeed such that a younger professor would not find it attractive to take on. And also something that's useful and significant, and can make an impact if successful. Impact is one thing I always wanted to emphasize, to do something that's useful and making an impact.

So I decided that what the semiconducting industry needed is a way to go beyond not only 0.5 volt power supply, but also 0.3 volt, and see a scaling path to 0.1or 0.2 volt. I think only then we will have a way of reducing the power consumption of ICs by order of magnitude, in fact even orders of magnitude. And that I believe will be needed -- if we're talking about the next 50 years. And I really believe that something very much like the CMOS today will still be used 50 years later, simply because we don't see alternatives on the horizon.

Aycinena: [INAUDIBLE]

Hu: Yes, and these are very thoughtful things. But using my judgment, it's just not going to make it in an attractive time scale. So for this reason, I really think we need to figure out a way to get essentially a CMOS-like device to go on for a long, long time. And if you talk about that timeframe, boy, reducing the power by 10 times is not even enough, much less than 30%. It's not just about heat management, or packaging. Not at all. I really see this as a green problem. So therefore, I actually call the transistor I started to work on the green transistor. I'm not sure the name will catch on. But the reason for the name is this.

Integrated circuit today already uses several percent of the US electricity. This is according to Department of Energy. And it's increasing very fast as we can imagine. Everything in the semiconductor technology doubles every x years.

Now, when integrated circuits use only 0.1% of the electricity of the world, doubling every few years OK. But when you get to a few percent it's going to become scary. But this is where I think we are-- it's almost a hidden time bomb.If we don't deal with that, how are we going to make this technological to go on for another 50 years? So that's why I decided to find the technology that can reduce the power by 10 times. And I thought tunneling would be the way to do it, or one of the ways.

Aycinena: And how does it look so far?

Hu: It looks still still promising. But after five years trying very hard and not being able to show a working demonstration, of course, in my mind it is a little less promising. But the question is, what's the choice? Therefore, I continue to toil on and fortunately there are still some sponsors believing these. These are selfless sponsors, they don't get any IP advantage.

Aycinena: Going back to the physicists, it's Einstein, who did or did not say, but it's attributed to him, it's 5% inspiration and 95% perspiration, So keep working.

Hu: I believe that.

Aycinena: So it brings me up to a topic which I had thought of earlier, but I just want to ask you briefly. I think in the last 25-30 years, in the span of your career as a professor of electrical engineering, a lot of the emphasis and appeal has been for people to study digital systems-- whatever part of the digital system discussion it is. And people have evolved away from studying analog. They've certainly evolved away from studying the power grid. And yet today, we see this full circle.

You're talking about the power grid. And I think it's very interesting. And are we seeing an uptick in people coming to university, either at the undergraduate level, or the graduate level, with their full intention that they are going to study the power grid? The optimization, the control, and the drain, from whatever sitting on that grid, pulling power. So what do you think? Are we seeing an uptick and interest in that, or are people who are doing traditional electrical engineering starting to look at it from a digital point of view?

Hu: All of that, and I say not too soon. It's a good thing that we're coming back to this very important part of the world infrastructure, to make that better. But I'd say that the way the student choose their specialization, and the government use their energy research money, by and large has been pretty smart.

Although I was a victim of the government pull back of the renewable energy research funding, and I was very puzzled for many years, as I get older and know more about how the economics of the world work, I become more understanding of that decision. When the oil prices is so low, it really won't change the path even if you throw a few hundred more million dollars into it.

But when the economic condition is right, I feel confident that the ingenuity of the engineers, technologists, can come to save the world. I think we will be able to do amazing things. I think it's good that we're coming back at this time to modernize the power grid.

I think there will be more incentives to do the renewable energy. I think it will be done. I also think semiconductor and information technology are still going to be the main engine for world productivityand economic growth. So I think this is still one of the best things for young people to consider as their arena for contributing to the world.

Aycinena: If there are market pressures for that, I think that gets translated into the number of students who do study technology. There's a natural feedback loop there.

Speaking of old technologies made new, I was in February at one the power stations up in northern California and not too far from Manteca. And it's a massive facility. It was built in the early '50s by the federal government. All the controls are still analog. So it's completely run on analog systems.

And you know what, if it ain't broke, why fix it? It's completely run by analog systems. It was very fascinating. They're perfectly fine. They work and they go on and on and on. So new isn't always better. It's just new.

So I want to make sure that we-- let's see what we have talked about. You've talked about the future of CMOS, the lithography limitations. One of my favorite topics, which may be only to me, is the whole idea of self assembling systems. And that comes back to the manufacturing question. What does that mean to you, the term self-assembling system. What do you think that means?

Hu: Well, that makes the two of us. That's an interesting topic to me as well. And I'll fill in a little more of the background of what this is about, at least to me.

I think we have been extremely focused on scaling size in the '80s and part of the '90s. And then in the last 15 years, we're very much focused on power, seeing that as the most urgent problem. And I think we will pretty soon find ourselves focused on cost, because making things cheaper is still something that the world expects. If we want to serve more applications, we have to continue to make semiconductors cheaper, not necessarily lower average selling price, but more function per dollar. We need to make things cheaper.

The tool that helped us to make things cheaper in the past was lithography, by and large. And that tool is becoming dull. So we need something to replace that. Of course, we still have the tool of making wafers larger, we still have the tool of building things in three dimensions, for example. And it's very exciting that next year we're going to see three dimensional flash memory product. And that's not going to be just a few layers, it will be 24 layers. Jumping from one layer to 24 layer in one leap. There's still room to grow in the future.

So this is going to take the blunt off the slowing down of lithography improvement. But I think we need more. The problem with EUV is that it's expensive. And yet it has some attributes that we cannot live without, but we need to supplement it. So this is where we get to self-assembly.

Self-assembly indeed means different things to different people. You are very observant when you asked me that question. To some people self-assembly means you just roll a lot of molecules into a vat and somehow a new organism, or form, or something will form by self-assembly. And that is not going to happen for semiconductor manufacturing because we do things still in a very complex and rigid way, and we have very specific ideas where we want molecules to go. Fortunately there's another way of thinking about self-assembly. And some people call that directed self-assembly, adding the word directed. I think it's a good descriptor so I'll use that. It says, let's not totally eliminate lithography, let's just use lithography fewer times in the wafer fabrication process. In other words, we use lithography, let's say EUV, to put down some anchor patterns. And this pattern is designed with what happens next in mind, in addition to what other things this step is designed to do.

The next step sends in engineered molecules, a particular shape, a particular length, a particular group of atoms at the end. —The atoms at the end will find and attach themselves--

Aycinena: Like with like.

Hu: —to the anchors that have been patterned by the first lithography step. The molecules are designed to serve a function such as an etch mask and to lay down new anchors for the next type of engineered molecules to attach to. At the beginning we'll be conservative with this technique, and we may have a hard time to tell the difference between this and what we call the self-aligned process.

But gradually we'll get more sophisticated about engineering more complex molecules, most likely organic molecule. DNA may have a role here, because we can manufacture them by polymerase. And this is the promise to me of self-assembly. It's a way to reduce lithography steps, and therefore reduce cost.

Aycinena: So assembling a carbon-based system has all kinds of interesting implications and exciting possibilities. But we're talking about something that we want to be a compute platform. And as married as I am to the idea of synthetic biology and all of that, because my initial background was in biophysics before I was in engineering. We're looking at something that's got an on-off that's a Boolean machine.

And those carbon-based things are not so good at the on-off. They're too much-- maybe I'm on, maybe I'm off, maybe I'm not-- too much in-between. So what I'm looking for, and I hate to restrict it to that, is that self-assembling system that will be a classic, probably crystalline-based on-off machine. So can we anticipate self-assembly for that very limited world, and you're saying, probably?

Hu: Yes, the organic molecules may be carrier vehicles that bring in the inorganic materials that perform the on-off function. The carbon and hydrogen may not stay on the wafer for good. I have enormous respect for the creativity of the technologist. And they may not be electrical engineers. You can see they may be chemists. Even though I failed in my biochemistry--

Aycinena: We're not going to hold that against you.

Hu: -- I mean organic chemistry, I hold no grudges. A few years ago at Berkeley, we hired our very first professor, in the EECS department, in the device group, who holds a chemistry Ph.D., because it’s important to bring a broad range knowledge to solve future electronics problems.

Aycinena: Absolutely. Well, and on personal note, we can get it out of this transcript, my son in law's Ph.D. is in chemical engineering but with an emphasis on protein synthesis. And I think he's also an epitome of bringing together classic chemical engineering, which is really an engineering and chemistry, and marrying it to the biology side of things.

Hu: Exactly, and you know the synthetic biologists side they are also trying to learn from what the EDA company has done. [INAUDIBLE] They want to emulate the semiconductors industry, the tools we have. If you Google there's actually quite a following of a topic called Bio-SPICE .

Aycinena: Well, actually at Design Automation Conference, I attended on a Sunday the nine hour workshop that had 17 speakers, about biological modeling. I'm simplifying but probably half the speakers came out of engineering and half came out of biology, and the topic material was all over the map. But it was an interesting bucket to throw a lot of papers in to. And I think clearly we're just at the beginning of a very long conversation between technologists, and I like that phrase.

So speaking of technologists, which are always human beings, and perhaps wrapping up on the human side of things. I know you have many interests if you have time outside of all of your technological innovations and involvements, above and beyond family, which I know is very important. I know you are a mountain climber, and I also know you have artistic side. So tell me about your sojourn into art, in to the visual arts, and how you became involved with that. And what your interests are in the visual arts.

Hu: Well, I'm an amateur painter. I paint water color. When I was a kid, it was a time and place where there were very few structured extracurricular activities. Some of my fondest memories were Sunday afternoons spent on copying pictures that fascinated me in the newspaper using pencil and paper.I was quite willing to spend hours doing that. But I never got any private instruction.

I must be in my '40s, with both children in elementary school, actually one in the middle school, when I decided to finally indulge myself and found a young painter who's a new immigrant from China to come from San Francisco to my home near Berkeley once a week and give me a lesson. And simply because of his training-- we started with the Chinese painting, not that I had any particular preference.

Aycinena: How is that defined? How do you define Chinese painting?

Hu: Very good question. I think the materials that you use is the defining characteristics. The paper allows the water, the color, as well as the ink, to spread easily . That creates a challenge to control the spread. At the same time it creates a fuzziness that in some ways is helpful to the expert and non-expert painters, actually. And I like the idea that there's something almost accidental about the result. So this is the type of a painting technique I started taking lessons for.

Not long after that, I first get to my wife Margaret to join me in the lessons. The two of us would paint together. The kids, after seeing us do that for a while, were willing to also join us. And what gave me a lot of pleasure, Peggy, is that through this process, my older son, Raymond's painting talent was discovered. And this is the biggest reward probably that I got from my sojourn into painting.

Shortly after Raymond joined us-- Raymond has Down Syndrome, and it's main symptom of course, is mental retardation. But he's a nice and happy guy, fun loving. However, he just wouldn't do things the way people usually do. He doesn't take directions well. I remember once we're all painting flowers and he was painting the glass cup that held the flowers. He wouldn't paint the flowers. I was unhappy that he would not take directions. But soon after Raymond joined us in to the weekly lessons, our teacher, Mr. Lampo Leong took me aside and said, “Mr. Hu, if you decide to quit lessons, that is OK, but let Raymond continue, please.” It gave my wife and me a lot of pleasure to discover Raymond’s talent. We’re very lucky to have Mr Leong as our teacher.

Aycinena: It's the people who refuse to follow the rules who are the innovators. So perhaps he's the true innovator in the family.

Hu: Indeed.

Aycinena: That's what I did-- go ahead.

Hu: And speaking of innovation or originality, I know that when I review paper submissions to conferences, often the conference will give you a form with two columns, one is quality of the paper, the other is originality. Originality is also valued when we review tenure cases, hiring. Originality is king in the electronics research community.

But through Raymond we get to know some real artists, not amateur painters. And I realized that these artists value originality even more than we do in the electronics.

Aycinena: I saw when I came in December, and I want to finish the conversation about the celebration in December. When I was on the Berkeley campus last December, and your family was there for the all day celebration. The art of all of your family was on display in the lobby. All of the paintings were beautiful. They were different. All of them were different. But clearly each of you has your own voice. But I wouldn't say any of that when the category of amateur. They were all beautiful works of art, all of them. So I'm sure it's been a wonderful conversation across your family. It sounds like for a number of years now.

Hu: You know, it's not easy to find things to do with your boys together.

Aycinena: But what a lovely--

Hu: --and this is something that we have all enjoyed.

Aycinena: It sounds like Jason, you're younger son, has also taken this into a professional-- I mean the whole idea of graphic presentation, and visual arts is something that he's obviously embraced.

Hu: Indeed.

Aycinena: So tell me about-- and that's how we first became better acquainted is last December, in a great honor to you, an all day celebration of your life's accomplishments on the UC Berkeley campus. What started the idea for the celebration, and I know you had to have had 12 or 14 speakers there. How was it constructed, and how did that happen? And you're going to have to brag on yourself a little bit. I can tell it's not comfortable for you, but do it anyway.

Hu: When our chair, Prof. Tsu-Jae King Liu first suggested the idea to me, I was actually embarrassed and resistant to that, because it's not like we do this for every colleague. So this is a real honor. I really didn't think I deserved this and didn’t want to let colleague go through the trouble doing this. But a few of them put up their own money. They say they want to do this for me. I was touched.

So they asked me to pick a time. And I pick a day that's five months after my birthday, to coincide with IEDM, International Electronic Device Meeting. So that's how it happened. And I was consulted about who to invite to give talks. And the suggestion to me was “invite your former students”. I thought about it, there are so many outstanding former students. The day was a celebration of their achievements as well as mine.

The symposium title was From Electrons to Electronics. There were some device physics type of talks, and talks on technologies including Flash memory, FinFET, and BSIM. The speakers are mostly my former students, sprinkled with a few Professor colleagues. Dado Banatao gave the opening remark. The symposium was held in an auditorium named after him and his wife. So I felt it fitting to invite him to open the symposium. And I know that you enjoyed very much, according to your blog, the music program provided by another former student, Ramune Nagisetty .

Aycinena: She works at Intel in Oregon.

Hu: Yes, she is Director of Intel Lab and the leader of her rock band.

Aycinena: Before we just close, I'm going to pull up for a moment, again, read from the EDA consortium press release celebrating your naming as a Kaufman award winner for this year. I'm going to quote from one of your former students, and let me see if I can find it, give me a moment. It's Klaus, and tell me again how he pronounces his name. "Klous Shoe-graph." So this is a quote from Dr. Schuegraf, one of your former students. And he is currently, which is a very great reflection on you, group vice president of the

EUV product development at Cymer but has a long industry background in manufacturing equipment, et cetera.

Hu: Indeed. Including CTO of Applied Materials.

Aycinena: Exactly, CTO of Applied Materials, and what they don't know about equipment for manufacturing probably isn't worth knowing. And again, I'm quoting from Dr. Schuegraf. "The Kaufman award celebrates Chenming Hu's contribution to the EDA industry for the BSIM compact models widely used to design all types of integrated circuits, spanning logic, memory, analog, and RF products. His technical contributions have profoundly affected directions in device technology, as with the FinFET all aspects of device reliability and non-volatile memory technology.

His graduates serve in senior leadership positions in industry and academia globally. Dr. Hu has served in key leadership positions at TSMC and SanDisk. With this award the semiconductor industry collectively applauds Chenming's monumental impact."

And I think it's not overstated. It has been a monumental impact. And I will say personally, and it's because I think of this magic you are bringing to going to different silos of your technical life, and taking up this piece of this piece of that, and knitting it together, and coming up with this, as I say, a whole which is greater than the sum of the parts.

Hu: I was lucky studying and then later teaching in the Silicon Valley in the '70s, '80s, and '90s. You cannot be luckier than that. And that's why I can do what I have done..

Aycinena: I think you're right, and the weather is so much better here than in Boston. So have we covered everything that you would like to talk about, do you think?

Hu: I want to thank all of my former students, and current students, and my colleagues and so many people that have helped me along the way. A person can be what he is only because of the other people that he has met in his life. And I have met so many good people. I'm lucky.

Aycinena: I'm sure that your father is very proud of you, and I'm sure your mother as well. But I think his suggestion that you go into electrical engineering was a good suggestion. He's proven him to be very right about that. So I congratulate you personally and on behalf of the industry for your contributions. It's wonderful. You really are the embodiment of an innovator, and for that I congratulate you. So thank you.

Hu: Thank you Peggy.

END OF INTERVIEW

