Oral History of John Slonczewski

Interviewed by:
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Bajorek: Well, welcome to this interview. This oral history records Dr. Slonczewski's contributions that resulted in his invention of the magnetic tunnel junction as well as understanding of spin torque transfer phenomena. The invention of the magnetic tunnel junction is especially noteworthy because it enabled the commercialization of the third generation of magnetoresistive heads used in all modern hard disk drives. We'll get started, John.

Slonczewski: Okay. Thank you, Chris.

Bajorek: Why don't you start by telling us about your family background, where you were born, examples of where you grew up and what schools you attended.

Slonczewski: <laughs> Yes. Well, I was born in New York and-- to Polish parents. They were ethnically Polish even though my father was not born in Poland; he was born in Switzerland. And I won't go too far into his story because his life story is extremely complicated but in the end he was-- as a youth lived in Brazil and then came to the United States and enrolled at The Cooper Union in New York and became an engineer and had a very successful career at Bell Telephone Laboratories. My mother had a simpler life but rather dramatic because at age 21 she left her village in Poland and arrived in New York City, and when she arrived she was informed that the quota for Poles for that year was filled and so she could not be admitted into the United States -- but then she did something quite dramatic. She escaped from Ellis Island and she got married and had two sons, myself and my brother, George, and after 15 years of living illegally in the United States she decided she wanted to become a citizen and so she learned that she had to go back to Poland and reenter in a legal way so she took my brother and me to Poland-- I was seven years old-- and thinking that if she spent the summer there as a summer vacation that she could then enter in a legal fashion, but there was a lot of red tape with her application for emigration because of her history. And so we spent actually eight months in Poland and so I had the pleasure of attending the first grade of school in Poland, and my memories of those days are really very vivid, much more vivid than my memories of New York when I was a little child. <laughs> So upon returning from Poland we did eventually move to Long Island and I lived on the north shore of Long Island and attended public schools there. I also took violin lessons and as a youth I imagined I would become a violinist but my lack of skill <laughs> pushed me in other directions. My father was very interested in physics and communicated his enthusiasm to me and so it was one of the early impulses-- early influences which led me to have an interest in science and particularly mathematics and physics.

Bajorek: Were there other potential career interests besides violin and mathematics in your youth?

Slonczewski: Yeah. It was the time of World War II and I had some sort of enthusiasm for being a naval commander but that was very, very unrealistic and did not really influence me in a real way. So on completing my high-school studies on Long Island I went to Worcester Polytechnic Institute and majored there in physics. On completing that, I was a little bit disgruntled with physics because the kind of quantum theory I was taught there was the old Bohr Theory which was not very satisfying, and so that led me to switch my major to mathematics at Rutgers University but after one year in mathematics I decided I could never really be a mathematician. And so I switched back to physics and then I learned the quantum theory in the correct way based on the work of Schrodinger and Heisenberg and so on and also solid state physics which determined my subsequent career really.

Bajorek: What was the focus of your doctoral thesis?

Slonczewski: Oh. My thesis was on the band structure of graphite and in that work I took the band structure of graphene, a single layer of graphite, and from that I projected what the band structure would be of the three-dimensional graphite. So it was rather the opposite direction of the modern interest because the properties of graphene itself are now much more exciting than the properties of graphite, but still the paper that I wrote on my Ph.D. thesis has been very well received and it's actually the second most referred-to paper that I have ever written.

Bajorek: Congratulations. Can you tell us what motivated you to join and then when did you join IBM?

Slonczewski: Yes. I joined IBM in 1955 after getting my doctorate at Rutgers University, and at the commencement the invited speaker was William Shockley who had won the Nobel Prize for his contribution to the transistor, and that as well as other influences led me to think that it would be very interesting to work on new applications of physics and so I went to IBM and IBM at that time was the leading computer developing company. And that year, 1955, was one in which there was a tremendous optimism in the United States. Science was very well supported by the federal government and there were jobs galore and I had many offers of jobs, and so I went to IBM because IBM was the premier company that was advancing computers.

Bajorek: Can you tell us about the range of research subjects you pursued at IBM?

Slonczewski: Well, yes. They were mostly related to the efforts in IBM to improve memory, and the computer memory of the time was based on ferrite cores and since I was connected with this group involved in that effort I investigated electronic properties of the ferrite materials which were used in ferrite core memory. At the time, of course it was interesting to increase the density of memory and so one approach was to simply replace the ferrite cores with flat magnetic films which could then be scaled down, and that led me to work on the physics of flat magnetic films and their interactions between films and the dynamics of the magnetic film reversal.

Bajorek: I remember I joined IBM in 1971 and I think we met over a discussion about so-called magnetic bubbles.

Slonczewski: Yes. In 1970, the Bell Telephone Laboratories proposed the magnetic bubble memory and so I got involved in that. I actually led a physics group that did experiments with magnetic bubbles and that was actually an exciting time from 1970 to 1980. That was when there was a lot of excitement about a magnetic bubble memory and I derived some equations for the dynamics of the domain walls that were involved. The word “bubble” was actually a misnomer because the magnetic domains were in the form of a cylinder in a very thin garnet film and the cylindrical wall of this so-called bubble had dynamical properties which I investigated. And then the experimentalists did many exciting experiments in which we really had a lot of fun, but one thing that turned out to be quite useful for memory was the so-called bubble deflection effect. In the cylindrical domain wall there is the magnetization vector within the interior of that wall and that vector lying parallel to the film could make a number of twists if you drew a circuit around the cylinder. The behavior of the magnetic domain was sensitive to the winding number. As a matter of fact, if force was applied to the bubble domain it would not move in the direction of the force but at an angle to it and that angle depended upon the winding number within the domain wall. So this property of the behavior of the domain based on the winding number was used in an exploratory magnetic memory called the bubble lattice file. And by the year 1980 IBM, particularly the group in California at the Almaden laboratory, succeeded in making a so-called bubble lattice file in which the information was encoded in the number of windings in the cylinder domain. But that year, 1980, was fateful for magnetic bubble memory because by that time the purely electronic DRAM, dynamical random access memory, had achieved extremely high densities and there was no end in sight for how the density of that memory would increase in the future so the efforts with magnetic bubble memory were completely abandoned in 1982. I had thought of the tunnel magnetoresistance of a magnetic tunneling junction as a useful way of detecting the presence of a magnetic bubble.

Bajorek: Yeah. That was sort of a side benefit of your involvement in bubble memories. Right?

Slonczewski: Yes, that’s true.

Slonczewski: But very soon after I thought of that the phenomenon was observed by Julliere working in France but the tunnel magnetoresistance was observed only at very, very low temperatures, just a few degrees kelvin. Still, I felt that there was really no fundamental reason why this effect should not be observed at room temperature and if it were then it would have some very significant applications. However, I did not actually apply for a patent on this effect and one of my thoughts was that here I have thought of this effect but there was this young man in France who not only thought of the effect but actually observed it experimentally and I didn’t want to be in the position of trying to take his achievement away from him. But another reason was that at that time IBM was not very interested in obtaining patents because there was the antitrust action of the federal government IBM did not want to appear monopolistic so it preferred to simply publish an invention but not attempt to patent it. I did publish three invention disclosures based on this phenomenon.

Bajorek: It seems to me that you may be selling yourself a little bit short. Although I agree that Julliere's work was significant, right, you were the first one to propose using such a tunnel junction as a field sensor. And I think you should not be shy about that concept because as we know today it's fully commercialized, right, and it's used in every disk drive for reading the data, right, in those disk drives. So I just want to make sure we set the record straight about that detail.

Slonczewski: <laughs> All right. Thank you.

Bajorek: Well, you're later on, right, at IBM still, right, for other interesting phenomena. When did you conceive of the spin transfer effect and was that while you were still at IBM?

Slonczewski: Yes. When IBM gave up on the bubble memory I was rather at a loss for directing myself but I had some interest in experimental work being done in Yorktown by Melvin Pomerantz on the magnetic films-- a pair of magnetic films that was coupled together by very thin oxide. And so I was interested in the theory of coupling by exchange and this interaction between different electrons of a quantum mechanical nature, and so I worked on the theory of this and coincidentally I was invited to Zurich by Heinrich Rohrer who had won the Nobel Prize for his scanning tunneling microscope. He wanted to make it sensitive to magnetic phenomena also and so he invited me there to work on the tunneling magnetoresistance that might be observed in the scanning tunneling microscope. And so from those two stimuli I worked on the theory of exchange interaction and also the tunneling magnetoresistance between two iron films separated by vacuum instead of any kind of material for the tunneling barrier. And so I did that work without any idea that there was such an effect of spin transfer torque but it was just something which I tacked on to this paper. It talked about the energy of coupling between the two magnetic films, that was one object, and the other object was the tunneling magnetoresistance. And then I thought well what would happen if to the torque if I would apply a current flowing through it and-- well, then I came out with this effect of the spin transfer torque. It was just like an incidental result of this calculation. The effect turned out to be very, very weak considering the very poor quality of materials for tunneling barriers that were available at that time and so I really dismissed it as being of no particular interest; it was just much too weak to even be explored.

Bajorek: Can you pin down the time? When was it you went to Zurich?

Slonczewski: Oh, yes. In 1987 I was a guest of Heinrich Rohrer in Zurich.

Bajorek: And I think later, right, you continued to evolve your thinking about the spin transfer phenomenon and applied to those ideas to-- also to memory, right--

Slonczewski: Yes.

Bajorek: Tell us more about how that evolved.

Slonczewski: Yes, there was something very much lacking in my thinking because barrier materials were simply of insufficient quality really to do good work. And so it would be natural to inquire about the sort of effects that would occur if you had a metallic spacer between two ferromagnetic metals. But I had a negative thought about this because I was aware of the fact that there is a strong static exchange coupling, which is propagated by the conduction electrons in the metallic spacer and the interesting effect which had been investigated was the coupling was a periodic function of the thickness of that metallic spacer. And so I simply assumed that well, any sort of an effect produced by an electric current surely would be negligible compared to what is there to start with. But it was really a very foolish thought on my part because previous to that I had been aware if this material is prepared in a very careless way there would be no coupling because the roughness of the interfaces would kill this oscillatory effect. And so for the next seven or nine years I just ignored the possibility that the spin transfer coupling <laughs> would be a significant effect, and then one day it finally dawned on me that my goodness, this will be an important effect. And so I worked it out and that was when I noted that if the scale is very small this effect would be very significant for memory application. But a further twist in this whole story is that I had promoted the idea of using metallic spacers. In fact I did an invention in which for writing the information I considered an electric current passing through a metallic spacer and then reading the information would be done with a magnetic tunneling junction in which the spacer is the tunneling barrier. But as things developed there was some amazing work in which very good-quality tunneling barriers were created. Using magnesium oxide for the barrier material gave really very good results in the end. The spin transfer through a metallic spacer was of no use. The much simpler and better-functioning memory element consisted of the magnetic tunneling junction itself in which one could do both the writing and the reading by passing currents through the tunneling barrier.

Bajorek: Now to clarify the matter, you also expected spin transfer to occur if you tunneled across a tunnel barrier. Right?

Slonczewski: Yes.

Bajorek: You didn't just expect it in that assisted with a metallic spacer.

Slonczewski: That's true, yeah.

Bajorek: You expect it in both.

Slonczewski: I had predicted it in the tunneling barrier before the metallic space, yes, but simply dismissed it because of the poor quality. So the real dramatic breakthrough for memory using the spin transfer was the theoretical prediction by Butler and company and another group in Britain of the-- of tunneling barriers using magnesium oxide and then the experimental achievement of this independently by Shinji Yuasa in Japan and Stuart Parkin at IBM.

Bajorek: The earlier, I think, magnetic tunnel junctions were based on aluminum oxide and titanium oxide, right, and I think some of the early exciting results didn't use the magnesium oxide, right. I think a group at MIT did it with aluminum oxide. Right?

Slonczewski: Yes:

Bajorek: And I think that provided impetus that then could spread out the work that led to the discovery of the MgO--

Slonczewski: Yes. So I'm not sure whether the magnetic tunneling junctions using aluminum oxide found any commercial use in recording heads.

Bajorek: Yeah. I was closely involved with those heads. The first-generation tunnel barrier heads were based on-- I think TDK was the first to release one with aluminum oxide and within months or weeks of each other Seagate released one with titanium oxide.

Slonczewski: Oh, I see, uh huh.

Bajorek: And then I think those oxides were used for the first couple generations and then, once the MgO results became known, everybody quickly adopted MgO for heads, and I think that that further provided impetus to using the MgO-based junctions for the MRAM--

Slonczewski: Yes.

Bajorek: Did you stimulate some MRAM work within IBM?

Slonczewski: Yes. Well, as you mentioned there was work at MIT. I've forgotten the gentleman's name who discovered aluminum oxide as a—

Bajorek: Moodera. Right?

Slonczewski: Moodera, yes, yeah, and then in Japan it was Miyazaki who observed it and those two results I learned about within one month; I got preprints from both groups. And so I informed Bill

Gallagher at IBM in Yorktown Heights about this and he became very enthusiastic about it because at that time he had been doing work in the Josephson supercomputer and the fabrication that he did together with Irving Ames and other people of the superconducting devices. Having had that experience he was convinced that he could make the arrays of the magnetic tunneling junction for memory using the aluminum oxide barriers. And so he immediately started this work up in Yorktown Heights and in fact there was a collaboration with a German company that sent some of their employees to Yorktown, and so this work continued for a long time but in the beginning the writing was done with the magnetic field caused by an electric current, not by the spin transfer, and after some years as the scale of those exploratory memories, as the density became larger and the dimensions smaller, then he did switch to the spin transfer as the more effective way of doing the writing.

Bajorek: Just to backtrack a little bit, can you remind us the date when you thought of the tunnel junction as a detector for magnetic bubbles so as a sensor? That was in the period I think when you were active in the bubble program.

Slonczewski: Yes.

Bajorek: What was the date of your concept?

Slonczewski: The idea came to me in 1974 and then it was two or three years later that I wrote up these invention disclosures which were published in the IBM—

Bajorek: Technical disclosure bulletin.

Slonczewski: Yeah. Thank you. <laughs> IBM technical disclosure bulletin but were not really patented.

Bajorek: We also talked about TDK and Seagate. They shipped their heads in 2004 so this is an interesting relationship. It took 30 years to commercialize the tunnel junction as a reader--

Slonczewski: Oh, yes.

Bajorek: --in disk drives. You conceived it in ’74 and the first-generation TMR heads shipped in 2004.

Slonczewski: Yes.

Bajorek: It was not an easy technology to commercialize but the industry mastered it in the end.

Slonczewski: Yes. These magnesium oxide barriers are really fantastic. The perfection with which they were fabricated is just amazing. They achieved useful barriers that were four atomic layers in thickness.

Bajorek: It's extraordinary the precision with which they'd learn how to make these films.

Slonczewski: Yes.

Bajorek: It's amazing. Now did you follow through with the MRAM application ideas with companies other than IBM? I think you were involved in working with other firms that were trying to commercialize MRAM. Right?

Slonczewski: Well, I didn't work with other firms but yeah, I had some contact with the Everspin Company -- there's another one; oh, I can't think of the name.

Bajorek: Grandis was it?

Slonczewski: Yeah, Grandis, yes. I had some contact with the Grandis Company. Well, before long there were many players in this sort of work, yeah, but then the really big push-- well, yes, I would say the history of it was that the-- there was a large semiconductor fabrication company-- I can't remember its name-- in which one group—

Bajorek: Was it Motorola perhaps? Motorola at one time made a big push for MRAM and then they spun off.

Slonczewski: Yeah. Well, okay. So perhaps that's the one that had one division which worked on magnetic memory but after two years they were spun off into Everspin and then it became an independent company. And so they made memories in which the magnetization was parallel to the plane of the layers but then later they switched to the perpendicular mode because they could achieve higher-density memory that way and so they were the leaders that actually marketed the memories.

Bajorek: I recall you mentioning in our private discussions that Everspin shipped a 64 megabit chip in 2012. I don't know if that refreshes your memory, and I guess maybe you could clarify for the future why did people get so excited about spin transfer versus the original ideas of using conductors with currents in them to switch films because the early MRAM ideas always use currents through wires, right, to switch through thin-film conductors. What drove people to be excited about spin transfer versus continuing to use the currents?

Slonczewski: Yes. It was the idea of increasing the density of memory.

Bajorek: That spin transfer could be scaled--

Slonczewski: Yeah, scaled better—

Bajorek: --better than the original ideas.

Slonczewski: Yes. So as a matter of fact the spin transfer could not really be used until the scale got down to something like the 100 nanometer range because of course in spin transfer you have an electric current flowing through it and the magnetic field of that would-- well, it would disturb neighboring films--neighboring elements—

Bajorek: Cells, yeah.

Slonczewski: --neighboring cells and so it was only after the fabrication technology reached the hundred nanometer scale that one could contemplate using the spin transfer.

Bajorek: John, I think later on in time you also thought of a different way of using spin transfer. I think you came up with the concept of using heat-assisted--

Slonczewski: Yes.

Bajorek: --spin transfer. Could you describe that and what motivated that thought?

Slonczewski: Yes. One potential problem with the standard use of spin transfer for writing information in a magnetic tunneling junction is that the flow of current through the tunnel barrier in time can cause-- can damage the barrier, and decrease the lifetime of this memory so by using heat I want to assist this procedure so that it would use less current. In this illustration I show here two memory element sites in the conventional way of using a spin transfer for writing, one has a reference magnet which is pinned by the presence of an antiferromagnet and then here is a tunnel barrier, and then the free magnet in which the information is stored is shown below here. So if an electric current flows through this device the direction of the current determines the orientation of the free magnet to write the information. Here I show the heat flowing through this gold layer and into a ferrite magnetic material, lying here below the flow of heat through the interface between the gold and the ferrite will create a spin current. This is now a current in which no electricity flows but the electrons with one direction of spin will flow upward and the electrons with the opposite direction of the spin will flow downwards so that there is no electric current flowing through this gold but there is a spin current and so when that spin current impinges on the free magnet it will-- since the spins are oriented in the horizontal direction they will cause the free magnet to magnetize orthogonally to the easy static directions of the free magnet. And so once the magnetization in the free magnet is horizontal then the electric current flowing through the magnetic tunneling junction -- the sign of that current will determine the information state. If the current is flowing downward, then the torque on the free magnet will push the moment downward and if the current flows and the direction is changed it will push it in the opposite direction and the assistance from the heat flow is-- from the fact that the energy-- the static energy of the free magnet is at a maximum in the horizontal direction. So the electric current only needs to be strong enough to determine whether the moment falls upward or whether it falls downward from this maximum of energy that's in the free magnet. So therefore the result is that the electric current required to write the information is very much smaller and this will prevent the damage to the tunnel barrier and the magnetic memory will have a greater lifetime.

Bajorek: It could also I imagine reduce disturbance of nearby cells. Right? As you reduce the current, that's beneficial not only in enhancing the lifetime but in reducing inter-cell--

Slonczewski: Yes. Yes, that's true. That will be the case also, yes.

Bajorek: Did you patent this idea?

Slonczewski: No, I have not patented this, yet. It-- I hope to. I still need to work out some details, and then I will apply for a patent.

Bajorek: But I remember somehow discussing this with you. You did apply for a patent using thermal--?

Slonczewski: Yes, I did.

Bajorek: But not this specific idea, was it more general?

Slonczewski: It was-- Well, I consider this to be a superior idea to the previous one.

Bajorek: Okay.

Slonczewski: Yes, in that case, I used the heat flow as an alternative to the electric current driven spin-transfer in actually writing the ones and zeros. But I think that this will be a more useful application of the spin current generated by heat flow.

Bajorek: Yeah, I think this-- to make sure I understand, I think you originally thought of using the heat flow to do this actual switching--

Slonczewski: Yes.

Bajorek: Of these memories. And in this case, you modified it to use it as switching assistance.

Slonczewski: Yes.

Bajorek: That is, you don't eliminate the electrical current altogether, but you reduce it.

Slonczewski: Yes, yes.

Bajorek: In the other case, you wanted to get away with no current.

Slonczewski: Well, of course-- and then with the-- if you try to use the heat to actually switch the information state, there is a difficulty that it's not so easy to change the direction of the heat flow. So, in this particular invention, the heat only has to flow in one direction. And the force created by the heat, or the torque created by the heat flow, only has to go in one direction. It pushes the moments to the direction in which its energy is at a maximum.

Bajorek: Right.

Slonczewski: Yeah.

Bajorek: Right. Has this phenomenon been demonstrated experimentally?

Slonczewski: No. No.

Bajorek: Is somebody working on it?

Slonczewski: Well, yes there is. Arunava Gupta, who works at the University of Alabama, has a contract from the NSF to explore this phenomenon. But he is a materials expert. And the first problem was to generate a very thin high quality ferrite film. And well recently, he has succeeded in doing that. And the next step of actually having heat flow through it, and so on, and observe the effect, has not yet been performed.

Bajorek: Is he part of that group that has been studying magnetic recording phenomena at--

Slonczewski: Yes, there is a group there. They call themselves MINT, yeah, M-I-N-T. I don't remember what the letters stand for. But there's a group there which studies materials for memory, yes.

Bajorek: I think it's run by-- currently, it's headed by professor Takao Suzuki.

Slonczewski: Yes, Suzuki.

Bajorek: He's the head of that effort, yeah. Well, the-- I think that covers, right? Did we leave anything significant that is-- as you recap in your mind your accomplishments and work, have we missed anything? Is there anything else you'd like to add to the accomplishments?

Slonczewski: No, I don't think there's anything more.

Bajorek: You think you've covered--

Slonczewski: Yes.

Bajorek: The ones that you wanted to do. Let's maybe switch the tone a little bit. As you now think back about all your accomplishments, do any incidents stand out that remind you of what were some of the most difficult challenges in making progress in your various projects? Are there any vignettes you could share with us?

Bajorek: What were the highlights? What were the lowlights, you know? What gave you the most satisfaction? And what gave you the most frustration?

Slonczewski: Well, there was-- actually early in my career at IBM, I was made manager of a theoretical group, which had about a dozen theorists. And I was very troubled by this responsibility because each of these theorists was working on his own research problem and had no connection with any interest in IBM. And so, I was baffled by that problem. And I didn't understand what I should do about that. My own interest was to look around me and see what was going on in IBM and to participate in something that would be significant. And so, I was puzzled as to what to do with this group of people. But the solution to my dilemma occurred when I got an opportunity to visit the IBM laboratory in Zurich, to spend a year there. And so, I-- and someone else took over my managerial responsibility. And so, I escaped that problem.

Bajorek: You escaped it through the back door.

Slonczewski: Yes.

Bajorek: What did you-- after that, you came back from Zurich, and you resumed your individual work? You didn't have to manage a group?

Slonczewski: That's when the magnetic bubble program came along. And I was assigned to that effort. And that worked out very well because there was an active device group that was making magnetic bubble memory. There were problems in the physics involved. And there were experimentalists that were doing experiments with the magnetic bubbles and theoretical questions about it.

Bajorek: There was a whole context for your work, right? This was a--

Slonczewski: Yes.

Bajorek: Try to develop the breakthrough in computer memories, right?

Slonczewski: Yeah.

Bajorek: And I don't know how you could get more applied than that.

Slonczewski: Yes.

Bajorek: In a company like IBM.

Slonczewski: So, the next ten years were really very delightful years of research at IBM. But at the end of the ten years, in 1982, when DRAM completely demolished any interest in magnetic memory-- well, of course, magnetic memory has the advantage of being non-volatile. Today, that's regarded as quite significant. But back in those days, there was no worry about consumption of heat in computers, or consumption of energy. So, the non-volatility was a trivial thing compared to the magnificent density that DRAM was able to achieve.

Bajorek: Clearly, we're excited about that period of magnetic bubble memory work-- related work, but which do you consider your most significant successes or success in your work?

Slonczewski: Well surely, it's the spin-transfer effect. And it's rather interesting that, during my early years there, let's say my first twenty years at IBM, I was conscious of these different application problems and the work that was being done in magnetic memory. And so, I could focus on that. But when that magnetic bubble project faded out in 1980, and I was kind of at a loss as to what to do, and the weird thing is that the really most significant thing I did was the spin-transfer. It was at a time when I had given up on magnetic memory, but somehow this great idea came about even though I was adrift. Oh, there is a dramatic aspect to that. There was one year when IBM suffered a tremendous loss, some eight-billion-dollar loss, and had to cut its staff. My manager thought that I was an ideal candidate to retire. Four levels of my management in Yorktown said that I should retire. But the technology director of the storage division saved my job for me. And it was only after that that I thought of spin-transfer. So, that extra several years in my career gave me the opportunity to do my best work.

Bajorek: Very nice. Who were some of the people you most admire in your career and why? Could you share those with us?

Slonczewski: Well, the two people I most admired there were Rolf Landauer and Jonathan Sun. Rolf Landauer, to me, was really a sensational person. He was a theoretical physicist who was really very creative in his own research work. But when he came to IBM, actually a couple of years before I did, he was aware of the fact that IBM was at a crucial point in its progress as a company because, up until that time, the machines were all electromechanical. And they used vacuum tubes. But Rolf understood that that was outdated -- that the future was in integrated circuits and replacing vacuum tubes with transistors and that sort of thing. And so, here he was a theoretical physicist. But he looked around, and he had a grasp of the big picture. And then he pushed people with his personality and by urging people and facing up to the problems required to make this big shift in IBM effort, which, of course, ended up very satisfactorily because IBM was by far the most productive company in the computer world. And then, on the other hand, he was also a great theoretical physicist. He wrote very interesting papers on electrical transport in materials which are very highly respected. And then the other person I admire is Jonathan Sun, who was-- had been my experimental collaborator. And he's still active today. He is a very active person who masters all aspects of his work. I mean he's done theoretical papers on magnetic memory related stuff and conducted experiments that are using all sorts of different instruments. And he just-- it's this kind of breadth of attitude, not simply making himself a specialist in one thing, but learning what needs to be done and learning the techniques required to attack all aspects of the research problems.

Bajorek: He collaborated with you at IBM?

Slonczewski: At IBM, yes.

Bajorek: He's still working with IBM?

Slonczewski: Yes, he's still working there. Yes.

Bajorek: Nice.

Slonczewski: Yes.

Bajorek: You're now retired from IBM?

Slonczewski: Yes.

Bajorek: Or you're still working there?

Slonczewski: No, I retired in the year 2002. So, that's how many years? I've been retired for a long time. Well, of course, for several years, even after retirement, I was an emeritus there. IBM did have a kind of emeritus program. But it's been now many years since I have actually been working on the premises there.

Bajorek: But you're still active-- continue to advance your work. That's my perception.

Slonczewski: Yeah, I do. I am active. But my rate of progress is rather slow, I must admit.

Bajorek: Could you share with us the-- any special honors and awards you received in recognition of your contributions?

Slonczewski: Yeah. Well, okay. The first award I got was at IBM, I received an award for the bubble lattice file, which, as I had explained earlier, made use of physical ideas that I had thought of. And then there was the IUPAP.

Bajorek: I think that also includes the Neel Medal in Magnetism.

Slonczewski: Yes.

Bajorek: That award?

Slonczewski: Yes. That was the IUPAP prize for research in magnetism, yes, and Neel Medal.

Bajorek: And I think-- are you a member of the IEEE?

Slonczewski: Yes, I am. Yes.

Bajorek: Did they think well of your work?

Slonczewski: Yes. I did receive an IEEE award for the spin-transfer work. And then the American Physical Society awarded Luc Berger and me the Buckley Prize for the spin-transfer achievement.

Bajorek: And the work here we're seeing now is to advance the spin-transfer-- development of the advanced spin-transfer ideas?

Slonczewski: Well, yes. So, I am most interested in this heat driven spin-transfer.

Bajorek: Could you share with us your outlook for the future of data storage and memory?

Slonczewski: Well, my own outlook is not very well-informed because I'm in my retirement. The intensity of my associations with people, with advances that are taking place, the intensity is rather low. So, my own ideas are bound to be kind of naïve. And I simply accept some of the things I read about magnetic memory-- the spin-transfer magnetic memory, it is, of course, non-volatile. And it can be embedded onto semiconductor chips. I've never understood why DRAM could not be embedded. But the magnetic memory can be embedded. And the fact that it is non-volatile means that it combines the memory-- the requirement that memory has to interact with a central processing unit in a very intimate way. And it combines that aspect with long-term storage. So, this is an advantage that the spin-transfer memory will have in the future. In my reading of the popular literature on these matters, I'm informed that there are something like eight different non-volatile memory technical approaches. And no one can reliably predict which one will be the dominant one, let's say, ten years from now. But spin-transfer memory is among the contenders.

Bajorek: Interesting to see how this develops in the future. What-- with your background and excellent experience, what advice would you give to a young person starting out their career in technology, physics, or engineering?

Slonczewski: My advice is nothing very unique. It's study hard and don't get too involved in digital things. But I'm a very poor person to advise-- to provide this sort of advice because when I started in my career, all doors were open. The '50s, it was just a few years after the end of World War II, the United States was the only part of the world that had an intact manufacturing establishment. There had been so much destruction in other countries. So, it was a period of tremendous optimism and no problem about going through college. And my simple thought was that, in my experience, I did not have to face these problems that ambitious students have today.

Bajorek: The enormous debts they accumulate.

Slonczewski: The enormous debts, yes. My father was a salaried person. And in those days, a salaried person could put aside enough money to send his children to college without saddling them with a debt. And today, it's atrocious when I learn of someone graduating and then owing a half a million dollars for his education and having difficulty finding a job. I'm afraid I cannot--

Bajorek: Reconcile yourself with that situation.

Slonczewski: Yes, exactly.

Bajorek: But I think you're saying if you're going to study, study the fundamentals.

Slonczewski: Yes.

Bajorek: Well, John, I think this ends the questions I had. Is there anything else that you wanted to cover in your interview, anything that we may have missed?

Slonczewski: No, I can't think of anything more. No.

Bajorek: Well, I want to thank you for the opportunity to be able to do this interview. And I wish you all the best in your continued pursuit of advanced magnetic phenomena.

Slonczewski: Thank you.

Bajorek: Hopefully, spin-transfer is not the last one you tackle.

Slonczewski: Yes. All right, thank you very much. I really appreciate the chance of exposing my thoughts in this way.

Bajorek: It's a pleasure.

END OF THE INTERVIEW

