Oral History of Dr. Yoichiro Tanaka

Interviewed by:
Chris Bajorek

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Bajorek: This is an interview of Dr. Yoichiro Tanaka, centered about the commercialization of the first perpendicular magnetic recording hard disk drive by Toshiba.

One of the most significant recent technology developments was the commercialization of perpendicular magnetic recording. Starting in 2005 perpendicular magnetic recording significantly facilitated a tenfold increase of data capacity in hard disk drives. Capacities of up to ten terabytes are the norm today. This breakthrough was made possible by use of a unique perpendicular magnetic recording medium known as the oxide medium which was first developed in Toshiba under the leadership of Dr. Yoichiro Tanaka.

Dr. Tanaka's team also integrated this oxide medium into the industry's first perpendicular magnetic recording hard disk drive. This oral history records Dr. Tanaka's contributions to these successes.

Yoichiro, could you start by giving us your name, a little bit about your background, your name, where were you born, where did you grow up?

Tanaka: Hi. This is Yoichiro Tanaka. I was born in the city of Yamagata, the northern part of Japan and grew up in the same city until eighteen. I joined Tohoku University in 1977. My major was the electrical communication and I graduated at Tohoku University in 1981, then continued to graduate school.

Bajorek: Which companies have you worked for? And can you give us a sense of your responsibilities and functions at those companies?

Tanaka: I joined Toshiba Corporation in 1983 shortly after I finished the master's thesis in Tohoku University. And since then I focused on the research of high density recording, high density magnetic recording including GMR sensors, especially PMR (Perpendicular Magnetic Recording) technology and its integration into hard disk drive systems. I have been leading the technology of high density recording for a long time. The other responsibility I had was development of the hybrid drive and architecture in the Silicon Valley with the team in Toshiba America. My recent responsibilities include leading the advanced storage system architecture design and research, especially for medical science data center applications.

Bajorek: Is this focus on system architecture and medical applications your most current responsibility?

Tanaka: Yes. This is my current responsibility.

Bajorek: Very good. Could you share with us who and what were your early influences both at college and at work on the decisions you made about research?

Tanaka: Professor Iwasaki was the inventor of PMR and also he was an advisor in my college days. He has been the biggest influence on the direction of my research career throughout my life.

Bajorek: If I'm not mistaken, your formal title or at least one of your titles at Toshiba is senior fellow. Is that correct?

Tanaka: Yeah, I'm a senior fellow with Toshiba Corporation right now.

Bajorek: Very good. I'd like to move with some questions about the commercialization of PMR. When did you first become interested in magnetic recording?

Tanaka: When I was small, I was very interested in radio communication and antenna. That was the great reason for me to join Tohoku University where the influential Yagi-Uda antenna was invented. Antenna communication is a very linear system and with a Maxwell equation you can make a design. I found that magnetic recording is also part of the communication system. It's a very complicated nonlinear system and I found there was plenty of potential for the growth possibilities of recording in the future. I redirected my interest to magnetic recording in my fourth year after graduate school and joined Iwasaki's laboratory.

Bajorek: I'm glad you did that because we have benefited from your contributions to magnetic recording. Did you pursue your Ph.D. studies on a fulltime basis?

Tanaka: No. I continued to work in Toshiba as a manager at the time. That was 2005. I became a part time student in graduate school to chase the Ph.D. That was an interesting and challenging time for me, as I completed the entire research of a new practical advanced PMR system. I came up with the idea that I should describe in my thesis to record all of my knowledge and findings for the people who will work on future storage systems and the sciences.

Bajorek: That one-year period during which you did your Ph.D. was between 2005 and 2006?

Tanaka: Right.

Bajorek: Was Professor Iwasaki your thesis advisory for the Ph.D.? Or did someone else advice you for the Ph.D. thesis?

Tanaka: No. Professor Muraoka in Tohoku University was my advisor of the Ph.D. thesis. Professor Iwasaki was my advisor for my bachelor's degree and master's degree thesis.

Bajorek: During your first stint at Tohoku.

Tanaka: Right.

Bajorek: When did you start to study the subject of perpendicular magnetic recording?

Tanaka: I started to study PMR when I joined Iwasaki's laboratory as a student in fourth grade of the university, undergrad school. That was the beginning of my career: academic research on PMR.

Bajorek: That was in 1980, right?

Tanaka: Yes, three years after the big invention of PMR. That was an exciting time for all of us in Iwasaki's laboratory. A very hot, hot, hot time for that.

Bajorek: Can you describe or summarize the factors that make perpendicular magnetic recording superior to longitudinal magnetic recording?

Tanaka: Two important points make PMR superior to LMR (Longitudinal Magnetic Recording). First, is the minimum energy state structure in which adjacent magnetic regions align in opposite directions to each other. That is a fundamental structure to make PMR very stable, and it brings many other advantages.

Secondly is the write structure compared to LMR with its ring-shaped gap. The PMR media is placed right underneath the single pole head and then pinched by another high permeability underlayer underneath the media. The media is right in the middle of the flux path.

Bajorek: What led you to focus on investigating the PMR medium itself?

Tanaka: In the very early days of PMR research Dr. Ouchi, who was a core researcher of Professor Iwasaki, invented cobalt-chromium perpendicular oriented media. We thought that was a perfect media in terms of alignment and orientation, but in testing we found some funny and unusual characteristic of the media. During the write process, the recorded magnetization was being destroyed by the tail effect of the write head. Recording has to be very stable at high density recording and I found something missing in that structure. We thought about what the media should be in terms of magnetic structure in the magnetic properties, and that is a big reason we focused on the media of perpendicular recording.

Bajorek: As I recall, one of the key conclusions you reached from that investigation was that you needed a much larger nucleation field. It was critical to solve that problem. Right?

Tanaka: Right. Nucleation field is the big factor for margin of the media. To resist against any disturbing field, thermal relaxation, demagnetization and the after effect of the write heads. For those disturbing fields, nucleation field helps the perpendicular magnetization in the media under very severe conditions. We found it is a must to have for perpendicular magnetic recording media.

Bajorek: Which media candidates did you study? And which one did you finally select?

Tanaka: Hmmm. We have had a very long list of PMR media candidates in our history. We started with cobalt-chromium which was the standard in the early days. And we pursued ternary alloys such as cobalt-chromium tantalum, cobalt-chromium something. At the same time, we worked on the longitudinal media which should have the large anisotropy energy. Cobalt-platinum was the base at the time, as well as cobalt-chromium. In order to make the grain structure of the cobalt-platinum we tried chromium and the other metal materials. Adding oxygen or oxide material was very interesting. Interestingly, it formed the very fine grain structure, and uniform grain structure. The fundamental idea was we had to use the cobalt-platinum base oxide grain boundary structure for future PMR media.

Bajorek: Who were your principal co-researchers at Toshiba?

Tanaka: In Toshiba Dr. Takashi Hikosaka was the leader of the media development, and Tomoko Taguchi, she is a leader in recording physics. These two co-researchers did a great job. We had a complete team, the three of us were the core of the team. In addition, we had Dr. Oikawa. He's a media expert**,** and Dr. Tsutomu Tanaka, another Tanaka, led the development of the media and Kotaro Yamamoto who was a very good design engineer for the drives. They were the fundamental PMR team in Toshiba.

Bajorek: How large was the overall group?

Tanaka: It was not big, just five or six people plus support.

Bajorek: And I had a question here about what led you to focus on cobalt-platinum-chrome-oxide but I think you've already answered it. Do you remember meeting with Tom Yamashita, myself and others at Komag in the early 2000s?

Tanaka: Yes, I remember. We gave a presentation at an academic conference about our cobalt-platinum-chrome-oxide media: the principles and the concept. We introduced that technology for open discussions. I remember that.

Bajorek: I ask this question because in that meeting you strongly influenced Komag's direction in the PMR media development. Shortly after that meeting Komag duplicated your oxide media, and we also saw the properties that attracted you to go to the oxide medium.

Tanaka: Oh, good. So you proved our concept.

Bajorek: Right. What were the top reasons for you to switch from LMR to PMR when you actually did it? What were the key reasons for doing that?

Tanaka: I worked on LMR. I studied LMR as well. When I was at the University of Minnesota the topic was "what will be the limit of LMR"? I had the idea that LMR was moving towards the limit of the physics of magnetics. In contrast, the PMR aligned with the physics: the higher the areal density the more stable the magnetization. The nature was helping PMR to go further, and that was the big finding on making the decision to switch from LMR to PMR.

Bajorek: The work here, eventually you did some of the work on the limits of LMR in Minnesota. Were you at the University of Minnesota? And can you tell us when that happened and which group you were collaborating with?

Tanaka: I worked for Professor Jack Judy to analyze the zigzag noise of the plated media, and how the noise is created. And we characterized in reading the noise structure with the heads. So those are my topics and found some limitations.

Bajorek: When were you at the University of Minnesota?

Tanaka: That was 1988 to 1990.

Bajorek: Did you enjoy their winters?

Tanaka: Very much. No other winter is better than this.

Bajorek: <laughs> Better than that. Can you give us a more specific sense of the design of the disk and how you selected the key ingredients of the disk like the soft underlayer, the ruthenium, the diamond like carbon lubricant, et cetera?

Tanaka: The most important part is the core magnetic medium which is cobalt-platinum based, and we can put additional materials like cobalt-platinum-chromium or some other materials to adjust it. Secondly, we have to make a granular structure and the grain boundary was made by the oxide. Oxygen was a taboo for longitudinal media. But the oxide created the beautiful grain structure and the grain boundaries surrounding the cobalt-platinum core magnetics. The grain boundary also includes a small amount of cobalt and controls the exchange coupling between grains. That helps the magnetization of the cobalt-platinum stand very stiff and stable in the structure of the media.

In order to have a better crystal growth of the cobalt-platinum we tried many materials as an underlayer, a control layer. We have found ruthenium is the best to control the cobalt-platinum crystal growth. Another challenge was the soft underlayer underneath the material to record with the head. The soft unerlayer is part of the recording head, which helps the write performance very much, but the big volume of that soft magnetic underlayer is a source of the noise. We had to eliminate the noise which was domains, so we tried multi layers and other stuff. In the experimental process, we tried many, many layers as a structure and finally reached a very stable, low noise structure as a soft underlayer. It was so thin multi-layer was down to ten-nanometer each. And we stacked tens of tens of layers on that. But experimentally it proved the domain can be removed. That's another proof of concept.

Bajorek: That was quite a breakthrough. Did you commercialize that soft underlayer? Or did you refine, simplify it before you went into manufacturing?

Tanaka: Together with the manufacturing partner by selecting the simplest way to avoid the impact on cost of the manufacturing processes.

Bajorek: Very good. Can you summarize which were the most important R&D steps, research and development steps that led you to the success? You know, examples like proof of principle, prototyping, qualifying, et cetera?

Tanaka: Mm-Hm. I have four very important steps: observation, physics, engineering and most importantly the philosophy to drive through the problems. Observation is kind of "listen to the phenomena of nature", and then find out the physics that lay behind it. Once we find the physics of how the nature works we bring engineering to make it real. We don't fight physics, we have to live with the physics. Engineering has to make it happen in a realistic manner or practical manner. There are many challenges and we hit many difficult walls which required that we have to have a clear will and a strong philosophy to break through. That's the very important steps on my research.

Bajorek: Probably not only clear but very strong will. Right?

Tanaka: Surely.

Bajorek: What were some of the main challenges that you faced during each phase of the hard disk drive program, the PMR program?

Tanaka: There were many challenges for me. Let's say, the early phase when we found the perpendicular recording -- traditional perpendicular recording was not stable enough. And that was the write stability aspect. And so we came back to the media design and write process. We were lucky to find what was wrong: demagnetization after writing was destroying the newly written transitions of the media. I remember that we had the bird's eye view.

In longitudinal recording highest areal density is the worst case, and longer wavelengths recording is the best case. In perpendicular recording, we chased the high density recording but forgot the worst case. Our observation of the phenomena told us to look at the worst case: that the isolated transition was destroyed by the tail effect of the write head because the media was not stable enough to resist the demagnetization field or disturbing field.

That was a very important step for us to work on, we focused on media with a high nucleation field which is very resistant to the disturbing field with high anisotropy energy and grain structure as well. The head and media have to be integrated, and heads were another challenge because we were not making our own. The write head is a very complicated structure. I remember I used FIB (Focused Ion Beam) to make the perpendicular single pole head like writer but it was never successful. We started a collaboration with the head supplier TDK, and that was a big change, working with professionals. That was the first challenge for us to get into the integration phase.

Bajorek: You had to convince yourself it was all stable. Right? Did you have to do some special testing? Or develop some special test to confirm the stability?

Tanaka: Yes. As usual, we tested heads and the media and its combination on a spin stand. It's a device level test, but this is not good enough. We started very early to integrate those devices and make a side by side comparison with an LMR hard disk drive. That was a very effective way for us to learn the features and the performances of each, and also gave us a great bird's eye view of the entire system.

It was exciting, I introduced our concept media cobalt-platinum-oxide media into the drive as well as perpendicular recording heads, and make it a stable structure. We tested in a wide variety of environments to gauge how strong, how weak. The experiments told us a lot, because LMR to PMR is a complimentary relationship in terms of the direction of magnetization. There is a complementary relationship between the two systems and observation guided us on what we should chase, what we should not chase. There were many kinds of brick walls, and our priority was “don’t fight the physics, fight the engineering”. We expanded the environmental range much farther beyond the hard disk drive specification, we found PMR performed better at both high temperature and low temperature. Even the spacing sensitivity was much better than the longitudinal recording. These were impressive and surprising findings.

Bajorek: I heard you once comment about an RDT (Reliability Demonstration Test), was that a special test that you developed -- your team developed for testing the reliability?

Tanaka: RDT is a normal procedure for products, so we took the prototype PMR drive into the product level RDT test to check the reliability. Any funny behavior found in the prototype had to be fixed, that was the reason to use RDT on the prototype.

Bajorek: You mentioned that you had key collaborations with Showa for the medium and I think it was TDK for the head. Can you give us a description of those collaborations and examples of what went well, and what didn’t go so well?

Tanaka: Toshiba has an R&D team and the capabilities, but it’s very upstream research, we focus on the principles and proof of concept in a very limited structure. Once we come out with this great idea, the concept has to be proven. We shake hands with partners, we have an open strategy to work together. Showa was chosen as a primary partner, and TDK was the partner for heads. We talked with them about a very short design-in cycle route in the early research phase together with them based on the proof of concept.

Bajorek: Can you give us roughly a sense of how much time it took for the three partners to declare success, to achieve success?

Tanaka: Yes, we started the big project in the year 2000. You remember we have completed the integration of hard disk drive and the announcement was made in December 2004. We launched the first products in 2005. So actually it took four-and-a-half to five years for the first commercial products at PMR.

Bajorek: That’s pretty fast. Four or five years is a long period in absolute terms but for breakthroughs like this I think that’s very good. Dr. Tanaka can you share with us how did you at Toshiba set the specific goals for the first PMR hard disk drive? How did you select what areal density to do? What drive capacity, reliability, cost, et cetera? How did you set those targets?

Tanaka: The prototyping platform was the two-and-a-half-inch disk drive, our mainstream product line. Side by side comparison of LMR products and the PMR prototype required that the same platform be used. It was very effective, both for product and product planning. Which products need more capacity? Of course, higher is better for everything. That was the year we were increasing the volume of 1.8-inch disk drives, those were the smallest at the time. We thought if we could increase the capacity of 1.8-inch disk drives we would have market opportunities, and even creating a market would be possible. We decided to integrate PMR technology into the 1.8-inch form factor and build 40 gigabyte single-platter and 80 gigabyte double-platter products. Those were the first PMR products.

Bajorek: I guess the predecessors in those products ended up being used in devices like the Apple iPod.

Tanaka: The portable media player was one of the biggest markets.

Bajorek: Probably the biggest application.

Tanaka: Yes, as well as the thin PC and video recorders. We expanded and enhanced the market. The areal density was 133 gigabits per square inch which was almost 33 percent higher than the state of the art longitudinal recording.

Bajorek: The reliability goal was to match or exceed LMR drives?

Tanaka: Reliability was better than LMR, even without reducing the flying height.

Bajorek: Yes.

Tanaka: So it was super.

Bajorek: Where was this first PMR hard disk drive produced? Which factory produced it?

Tanaka: At the time we had three factories manufacturing in the Philippines, Thailand and China. We started a production line in Tokyo and then took the drives into the other factories.

Bajorek: I think we covered this: who were the main customers and you said the portable audio player, PC and video cameras.

Tanaka: At the time we were focusing on portable products: notebook PC, portable media player, video recorder and car navigation systems. Those were our focus and we brought along enterprise products later, after acquiring Fujitsu's hard disk drive.

Bajorek: When did Toshiba acquire Fujitsu, what was the timeframe?

Tanaka: It was 2009.

Bajorek: I don't think Toshiba bought all of Fujitsu, just the disk drive operation.

Tanaka: Disk drive operation. Yes.

Bajorek: I just want to make sure we didn't skip this. Can you give us an example of the best success as well as the worst failure along the way in getting to the goal line?

Tanaka: The best success was bringing the new PMR technology for enhancing high density recording for a big capacity in a small body. It enhanced the market, new growth of portable media player and video recorders. Our products created a generation of new and emerging products. That was fun.

The worst failure was in my research process. We started with cobalt-chromium traditional PMR media and we tested a variety of features and the performance. In the early days we found spacing sensitivity was much worse than LMR. Many people, including me, misunderstood that is a fundamental feature of perpendicular recording but it was not. There was a misalignment between the proper design of PMR media magnetics and the write process. The paper I wrote on this feature was my worst experience. I later wrote a new paper to validate that perpendicular recording is much preferred and the low sensitivity to spacing in PMR.

Bajorek: The trick was to have the high enough nucleation field. And I gather that oxide media didn't have this problem.

Tanaka: No.

Bajorek: Right. Can you give us a sense of the progress that has been achieved since the first 2005 introduction? Now, we have just crossed the tenth anniversary. How did things go over the subsequent ten years?

Tanaka: It's a happy anniversary. Ten years, eleven years. Since we launched the first PMR drive at 133 gigabits per square inch the areal density has grown to six-fold higher than the original. Finally, it has reached the one terabits per square inch in a short period. An areal density of one terabit per square inch was a dream, and our company is the first to reach that in a product. We also expanded usage of hard disk drives in a variety of fields, not just the small portable disk but also mainstream PC and enterprise drives. Within four years or five years all of the products switched to PMR from LMR. That was an amazing speed.

Bajorek: So by roughly after 2009 everything was…

Tanaka: PMR.

Bajorek: Can you give us a sense of today's hard disk drive market measured in units?

Tanaka: Right now the hard disk market is 400 million units plus, depending on the year and the quarter. Toshiba has an 18 percent share currently, position number three.

Bajorek: What's your outlook for the future of PMR?

Tanaka: The magnetic recording physics is still valid. And with the proper engineering such as assisting energy for the write process and squeezing track width by finer lithography process of the head or two-dimensional recording magic, and advanced signal processing technology I think we can go further.

Bajorek: Very good.

END OF THE INTERVIEW

