Oral History of PMR Inventor Team:

Hiroaki Murakora and Yoshihisa Nakamura

Interviewed by:
Yoichiro Tanaka

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Tanaka: One of the most significant recent technology developments was the commercialization of perpendicular magnetic recording (PMR). Starting in 2005, the adoption of PMR facilitated a tenfold increase of data capacity in hard disk drives (HDDs). HDD capacities of up to 10 TB are the norm today. Researchers at Tohoku University made key contributions in the invention of PMR as well as in the understanding of the physics of PMR and requirements of heads and media. This oral history records the contributions of Professor Yoshihisa Nakamura and Hiroaki Muraoka to the success of PMR.

Well then, Mr. Nakamura and Mr. Muraoka, thank you for joining us here today.
First of all, Mr. Nakamura, please tell us about yourself.
Tell us your name, your birthplace and where you where you grew up.

Nakamura: I am Yoshihisa Nakamura. Thank you for having me today. I was born in Tokyo. My ancestors, up to my father's generation, all lived in Takizawa Village, Iwate Prefecture so Takizawa Village is where I am rooted.
For junior high school and high school, I returned to Morioka in Iwate and I spent my youth there, so I don't regard myself as being from Tokyo, I consider Iwate as my home.

Tanaka: Please tell us about the university you graduated from and your expertise.

Nakamura: I graduated from the Communication Engineering Department, Tohoku University, in 1963. Immediately after graduation, I joined the Graduate School and completed the doctoral course of Electrical Communication Engineering in 1968. My specialty is communication engineering.

Tanaka: Could you introduce your academic career, positions, and responsibilities?

Nakamura: Yes. After I graduated, I started to work in the Research Institute for Electrical Communication (RIEC) at Tohoku University. I was assigned to be an assistant, then an associate professor, and finally a professor there. My last career at Tohoku University year was as a director of RIEC for 3 years. I retired from Tohoku University in 2006 and joined the Japan Science and Technology Agency (JST). I worked for JST for two years as a director of Miyagi Plaza. After JST, I was the president of Iwate Prefectural University for 6 years. Currently I am a fellow at the Iwate Industrial Research Institute.

Tanaka: I see. Thank you very much. Could you tell us who and what influenced you in your early days of research while you were in university?

Nakamura: I would have to say, Professor Iwasaki was my direct advisor and Professor Kenzo Nagai, who came before Professor Kenzo Nagai, and whom we all regard as our “Father”, the person who was the first to start magnetic recording in Japan. I also remember Dr. Katsuya Yokoyama, who worked at NHK Science & Technology Research Laboratories at the time, and was 5 years my senior. He educated me in many ways. He always told me to support Professor Iwasaki’s outstanding success or, as we say in Japan, “Make a man out of him”. Outside of the university, Dr. Junsaku Yoshida sincerely took care of me. He worked on a variety of things at the NHK Science & Technology Research Laboratories. Among many others, these are the key persons that come to mind.

Tanaka: Could you explain your current position and responsibilities?

Nakamura: I do not have such a big role now. I’ve been asked to supervise research at the Iwate Industrial Research Institute as an advisor and fellow so I occasionally provide advice.

Tanaka: I see. Thank you very much. Moving on, let me ask Professor Muraoka for some information. Could you give us yourself, name, birthplace, and where you grew up?

Muraoka: I am Hiroaki Muraoka. I was born in Shimonoseki, Yamaguchi Prefecture. I soon moved to Hokkaido and grew up there.

Tanaka: What university did you graduate from and what was your major?

Muraoka: I graduated from Tohoku University, the Electrical Communication Engineering Department in 1976. Later, in 1981 I received a doctoral degree from the Graduate School of Electrical Communication Engineering.

Tanaka: Could you tell us about your career and positions?

Muraoka: Immediately after I graduated, I joined Matsushita Communication Industrial Co., to develop flexible disk drives and worked there for 10 years. In 1990, I was invited by Professor Nakamura to RIEC and have been there since then.

Tanaka: What is your current responsibility?

Muraoka: I am a professor at RIEC.

Tanaka: Thank you very much. First, I would like to ask about the early stages of magnetic recording research. Could you tell us the year you entered the university, and I believe you've already mentioned this but, your major, and your interests of study there upon enrollment?

Nakamura: When I entered university, I did not have a specific goal. My father was an engineer, of radio communication. I was advised to choose Tohoku University and I thought this could be my path.
Well, as I pursued this, and there were various experiences which led me to it, I became deeply interested in the tape recorder. One experience was this. My father was working for Sony, whose name was "Tokyo Tsushin Kogyo" at that time in the 1950s. During that time, immediately after Sony launched the tape recorder, he brought one home and I made a recording for the first time. That was when I heard sounds and voices that sounded completely different from what I expected to hear and I was taken by surprise. This was my very first impression of the tape recorder. In my junior high school and high school years, I was in the drama club. We used a tape recorder to record sound. We had slides and we recorded voices, dialogues and music to play with the slides. We took the slides and the recordings and visited places such as orphanages to entertain. This was another experience with the tape recorder. I started university and joined the broadcasting club and of course, we used the tape recorder to make radio dramas. We often had many opportunities to use the tape recorder. Especially when I was in university, we could not afford to waste magnetic tape so we tried recording at low tape speed. That resulted in poor sound quality. The seniors in the club and I wondered what caused the sound quality to be so poor and discussed if there were any ways to keep the sound quality from worsening. These are the reasons I became interested. Open lab in the Electrical Engineering Department happened to be held during my junior year in university. I walked around the open labs and when I reached Professor Nagai's lab at the end they played me a jazz music recording made on a newly developed Fe-Co-Ni metal particle tape. It sounded great and it made such an impact on me that I decided to join this lab, which ultimately led to what I do now.

Tanaka: So you were fond of magnetic recordings from an early age.

Nakamura: At first, it wasn't a conscious decision, I wasn't in search of something different but I was gradually drawn into it. As a result of my experiences.

Tanaka: So the when and how of your interest in magnetic recording research is as you described it just now?

Nakamura: Exactly.

Tanaka: Could you give us a summary of your doctoral thesis as well as describe the challenges you face in your research?

Nakamura: So, I started from wondering why sound quality degrades at a lower speed and when I was an undergraduate I was tasked to elucidate the AC bias mechanism invented by Professor Nagai for my graduation research, however, in graduate school my research was in short-wave recordings, in short, to study the recording mechanisms when recording high-frequency audio, as in speech. At that time, when we took various measurements, especially with long frequency, the saturation characteristics showed that normally output saturates as it increases, however, with short-waves, once it reaches maximum output, it would suddenly drop. There was data at the time that showed that the cause of the drop would depend on wavelengths and, of course, the thickness of the recording layer so we researched short-wave recordings mechanisms to elucidate. From my Master's to my Doctorate, my research theme was "Research on magnetic recording mechanisms in short-wave ranges". At first, we studied why this happens by applying the conventional method we all learned at that time. We started with head magnetic field distribution, followed by magnetic field change for magnetic tape when passing through head magnetic fields. In short-waves, the field polarity changed many times. At the same time, we conducted a detailed study of the magnetization state inside the tape to find out magnetic characteristics, how hysteresis loops are tracked and what happens to remnant magnetization. That's how we discovered that the magnetic charge distribution on the surface and that on the back side were not in alignment. In the worst case, there were magnetized states where the surface is positive and the back side is negative. We found this to be odd. We came up with an idea that maybe it closes inside, in other words, we thought that perhaps a closed magnetic circuit was being created so we repeated the experiment. Measurements of the recording characteristics showed that, in fact, there were times the output was at zero. Then were would be slight increases in output from there. In short, we called this the null point, we found this so we discovered that closed magnetic circuits were being created in the magnetic tape. We realized that this was the origin of recording demagnetization from the point of view of the phenomenon so the next issue was finding out why such a phenomenon would occur and we thought considering only longitudinal components would not be enough, that we should study them from a vector aspect. We introduced spheroid particle models such as the "Stoner Wohlfarth Model" to study vector magnetization but in doing so, when the thin magnetic tape passed through the head area, the entire magnetization was magnetized perpendicularly, if we took only the head magnetic fields into consideration. If we took only magnetization distribution into consideration. And so we thought there was something wrong. Since it was a thin magnetic tape and longitudinally magnetized, we thought the magnetization would be longitudinal. So we knew we must be missing something. If we considered only demagnetizing fields, magnetization would only become smaller so while the tape was passed through, the vector magnetic fields were rotating near the head this way. We thought that the demagnetizing fields should be included in each process, realizing that we had to include the theory of self-consistent magnetization so we studied how to calculate it and implemented it.

Then we worked on a variety of vector calculations and incorporated them and we took a theoretical approach to uncover the relationship between the longitudinal components of the magnetization, what we called the scaler magnetization, and the vector magnetization, even though we were unsure if this was correct. In the end, I wrote a paper that incorporated the quantitative explanations for why the recording demagnetization loss happens. I somehow found a way to explain it quantitatively so I think that was the most challenging part of it.

Tanaka: Thank you very much. I believe there was a course of events in the research of magnetic recordings that you supervise at the RIEC at Tohoku University. Please share some of your observations.

Nakamura: Basically, Professor Nagai started research on magnetic recordings in 1932. It was still in its early stages when they were still working on wire recorders which I am not familiar with, however, this research led to the AC bias, in other words, signals at the time were in audio so by improving the signal quality of the audio, some say it was just by chance he discovered AC bias. And now its history. Professor Nagai filed a patent and thanks to his patent, Sony had the patent after World War II and made tape recorders. When Sony was about to start selling their tape recorders, a lot of tape recorders were being imported from the US, I believe it was Ampex. Recognizing this as a problem, Professor Nagai immediately visited the GHQ of the American Military and presented the patent he owns and this is where I think "only in America", the US acknowledged the patent and allowed Sony to sell them. That is the history. Therefore, this type of industry-academia collaboration is a long-established practice at Tohoku University, and at Nagai Laboratory. Professor Iwasaki continued the legacy. I believe Professor Iwasaki worked for Sony and later returned to Tohoku University to research magnetic recording. Through his research activities, he found there were limitations to the hamma hematite magnetic tape available then and that the tape needed to be thinner. In order to make it thin, the saturation flux density needs to be increased and so do Br and Bs. Since just increasing Bs will create a stronger effect of demagnetization, coercive force should also be increased, therefore the magnetic characteristics were increased, maybe about two times more. FeCoNi was positioned to support the concept as a new tape material. I joined the lab shortly after this so it was a lab that had inherited this time-honored tradition. Therefore, there was always an industry-academia collaboration, a lab environment that welcomed many visitors from industries and universities.

Tanaka: I see that the lab conducted a wide range of research including in industry-academia collaborations.

Nakamura: Absolutely. As a university, I feel they consistently provided a very privileged environment, and an extremely blessed environment for engineering research.

Tanaka: Yes. Through your research, you have evolved the process to verify magnetic recording theory through simulations. Could you elaborate on this?

Nakamura: As I said earlier, I could not accurately explain magnetic recording without the vector magnetization processes. The influence of the diamagnetic field, at that time it was called the diamagnetic field, needed to be included properly to solve the issue self-consistently. And it so happened that at this time the university installed a large-scale computer and we were well on our way into the computer development era. Dr. Toshiyuki Suzuki was very good with these things. I guess you could say he was my co-worker although he was older than me, he joined the university two years after I did. He worked very hard to develop computer programs with very good results so I would say this was the early stage of computer simulations. This is how it started. I wanted to do this properly, at the level of animation-like visualization. Although there was a time when this was temporarily suspended. Another thing was that we wanted to properly prove with the simulator was that a vortex forms in the magnetic layer, that a rotation magnetization mode is created and so later, at the lab where many graduates of the lab such as Dr. Tagawa and others developed a simulator called then, “SMART” - I have forgotten what this was an acronym for -- and this simulator allowed us to study a variety of PMR mechanisms.
I wish I could actually show you. I do have it with me if you need to see it. You may need to cut this portion out later but...

Tanaka: Thank you very much. Next, I would like to ask you about PMR research.
First of all, could you talk about the process leading up to the idea of perpendicular recordings and when you started thinking about this and the ideas that you had?

Nakamura: Well, there were two courses of events. One was Professor Iwasaki’s idea. This would be the fact that a rotation magnetization mode is created. Professor Iwasaki wanted to see it. We cut the cross-section of the magnetic tape and made every effort to observe this through a microscope using the bitter method, the students and assistants. Then, we came up with the idea that if we could somehow apply a perpendicular magnetic field to the rotation magnetization mode, the magnetized state would be converted perpendicularly and we may be able to read that, so, I think it was the conversion of the magnetization mode, we started on the idea of using a method of conversion to read, to read what was perpendicularly converted. So I thought about something like a perpendicular head to get these readings. I worked with Mr. Watanabe on this. Separate from this, I was working on the self-consistent calculation, as I mentioned earlier. However, I was unable to perform calculations on a large-scale computer on my own, it was above my skill set. So I wondered if there was an easier way to do it and I explored other simpler calculation methods. One of the ideas was, there’s something called the Preisach model and I simplified the Preisach model and I made a model by extracting only the characteristics of the magnetization curve, the hysteresis loop, similar to linear approximation, and implemented it in the

computer, in short, in the computer or should I say I implemented an extremely easy way to calculate self-consistently to calculate magnetic transitions, that was an idea that I came up with.
At the time, our lab was also doing experiments on in-plane thermal recording using co-alloy magnetization films to try to study the mechanisms theoretically. So we tried to compare that with something written in using a head, we did calculations like this at one time. I believe this was around 1974. Once the calculations were done, and it was same with heat as well, the one written with a head, there were several kinds of data but the results showed, for example, even if the spacing was made smaller and smaller for higher density, the transition width would never be zero. It will just be a certain fixed value. So I thought no matter what we did, it was impossible for the transition width to be zero. It was the same with thermal recordings as well. Just around that time, research on optical recordings, optical magneto-optic recordings, prior to that, bubble memory and research using perpendicular magnetization films and perpendicular magnetic anisotropy films were being conducted around us. So I thought, if it can't be done with a longitudinal film, maybe perpendicular is better so I told Professor Iwasaki that I wanted to try perpendicular recording. Professor Iwasaki happened to be working on magnetic mode conversion, converting to perpendicular mode so we decided to give perpendicular a try, I think we started around 1975.

Tanaka: Very interesting, sounds like a fusion of technological events.

Nakamura: Yes, you did. Well, at the time, not only ourselves, but also Dr. Speliotes, Judy or Mee were also doing calculations on the relationship between Brδ/Hc and transition width, experimental calculations and they all ended up with a certain fixed value. It would drop straight down. It wouldn't drop at 1/2, it would always go back up somewhere. I found data like that which deepened my convictions.

Tanaka: Could you explain how you had discovered the superiority of perpendicular recording over longitudinal recording?

Nakamura: Back then, it was difficult to talk about this and that when it came to theories. Later, a long time later, it could have been just before I retired, I had a little time so I tried some theoretically. But back in the day, the experiments took up all my time and energy. Every time we conducted an experiment, we got better results. The recording density characteristics showed improvements and I was focused on the experiments so I never had any negative thoughts. I believed in what I was doing and dedicated myself to it.

Tanaka: What was the greatest trigger that made you focus on perpendicular magnetic recordings, what made it your focal point?

Nakamura: Indeed, in short, I tried writing using a perpendicular magnetic head, at first something like gamma hematite to look at the output of magnetizing conversion and then we found the Co-Cr alloy, then all different kinds of tools became available and the more experiments we performed, the more the data improved. So inevitably, it was clear this was the way to go. I could not afford to pursue something else, nor did I even consider thinking about anything else.

Tanaka: What do you think was the biggest breakthrough in the process of inventing perpendicular magnetic recordings?

Nakamura: Well, it was the single-magnetic-pole head and at first, I simply used a thin supermalloy sheet, they were 10 microns or 20 microns, maybe a little thicker. I wound it up with coil then wound up the thin sheet and a thin rectangular sheet with coil and used it as a head but it wasn’t good enough for writing, even on gamma hematite tape, so once I realized that I got creative. I tried making the base thicker or placing a large soft magnetic chunk on the opposite side to create an image effect, I conducted various experiments, I did many things I learned from electromagnetism but they did not work. So when I started wondering about what to do, to put it simply, the single-magnetic-pole-type main pole, which we started calling it later, the magnetic field generated from the tip of that was what was important so I thought of ways to directly excite it. I couldn’t wind it up with coil so on the opposite side, at first I used supermalloy but then I used ferrite wound in coil on the underside and excited that. I excited the tip of the main pole this way. I inserted a medium in between for excitation. It did seem a little like it was the wrong course of action but when I tried it the recording sensitivity improved significantly. It made recording easier. So, since then, I used the auxiliary pole driven single-pole-type. At the same time, back then, as I mentioned before, I used a cobalt alloy film and tried thermal magnetic recordings and I tried different materials but with the longitudinal ones, the recordings were substandard so Mr. Ouchi, who was working with me, and I faced extremely tough challenges. So when I happened to ask what it is like in the perpendicular direction, I heard that the characteristics were good in the perpendicular direction, that it is showing good square characteristics. Of course, it is diagonal in the demagnetizing field but it showed good characteristics. So, well, I thought why not try writing on something made for cobalt, a Co-Cr film made for optical magnetic use and at first I recorded using a ring head and I got significant output. Eventually I realized that if I used single-magnetic-pole-type heads I can get more output and an increase in high density as well. So I thought if I combined the two I would be able to make perpendicular recordings so I believe this was the start of the next step. Then, eventually in the next step I was not satisfied with the recording sensitivity which made me think about what to do about it when we came up with the idea of the double-layered film and with this the recording sensitivity increased a digit and the output increased a digit as well so I think this was our biggest breakthrough, I believe with this we finally had the basis for perpendicular recording.

Tanaka: I see. Thank you very much. At the lab we conducted trial experiments on perpendicular heads and well, we created mediums, I think we tried many things. What would you say were the difficulties or challenges of trial experiments at the time?

Nakamura: Let me try to recollect what those difficulties were... Well, from my point of view, I recall we faced difficulties and we weren't making the progress we wanted. With heads, this is something many people know about but we had an impressive technical expert, Mr. Watanabe, and the heads that he created showed characteristics that were very much like what we were hoping for. That was a very positive thing for me, you could say I was very grateful for that. With mediums, Mr. Ouchi worked through a lot of hardships and I think we had only begun to start working with them but we were finally able to purchase a sputtering machine with the scientific research fund and I vaguely remember we struggled to learn how to use it. This may be something Professor Muraoka may remember better since he had just joined the team around that time.

Muraoka: Yes, you did. Well, I was tasked with the experimenting tape reading/writing. Professor Ouchi provided the medium to cut into tapes and to measure. From the perspective of the one handling the experiments, I recall struggling with azimuth alignment. If the azimuth is not in complete alignment during recording and playback, the D50 would not increase, in the reproduction effect. If it was a mechanism with a backlash it would go too far and next on return, it would go too far. In other words, it would never align at the right point. Making those adjustments were extremely, what's the best way to describe it, I recall it was hard because the alignment was required to be done with the sensitivity of using fingertips. So, since the medium comes into contact with a thin film, the thin film is in contact without any protective film or lubricants during recording/playback, the medium breaks. So we needed to take measurements before it broke and because the flexibility prevents it from being aligned perfectly with the head, it was difficult to get a clean envelope so we struggled to figure out exactly where to target to get the measurements.

Nakamura: At the time we used tape devices for our experiments. In other words, we used normal gamma hematite recording tapes and inserted spattered CoCr in between, I believe they were about 5 cm long, so we inserted the approximately 5 cm piece of that using splicing tape and we observed that. That's why we were only able to observe it for a brief moment with the memory scope. I believe that is the reason we struggled more in making adjustments. In that sense.

Tanaka: It must have been quite a struggle.

Nakamura: However, after considering various things that I mentioned earlier, we tried the experiments and the recording characteristics steadily improved. We celebrated each time, we got together and celebrated with drinks. We frequently had get-togethers, probably once a month, I recall we were celebrating over drinks a lot back then.

Tanaka: With heads and mediums, you must have come up with many different types of configurations so tell us about what kind of methods you came up with and the trials you conducted.

Nakamura: People were doing all kinds of things around us but we focused on the single-magnetic-pole head auxiliary pole exciting shoulder and cobalt chromium. Back then, we didn't make any significant changes in the materials for cobalt chromium.

Muraoka: We optimized the Ms.

Nakamura: I believe we tweaked the magnetic characteristics a little.

Muraoka: We also tweaked the thickness of the film.

Nakamura: Also, there's the double-layered film. I mentioned backing the cobalt chromium with soft magnetic film, and creating a double-layered film improved the characteristics. From there on, we didn't make any huge changes. I don't think we made any changes for the experiments using tape. And what else... I think you asked me something else... Did I provide you with the answers to your question?

Tanaka: Yes, you did. Yes. In that case.

Nakamura: So, there are many other options such as using a ring head for writing. Later on, there was a time when I strangely hesitated and thought about using the ring head. But I knew from the beginning that that was not a good option. Given the waveform patterns and it was difficult to use for many reasons. When comes to the ring head, for me, it was something I knew not to use from the beginning. I didn't give it a thought.

Tanaka: We intensely focused on the combination of the single-magnetic-pole-type perpendicular head and double-layered medium from an early stage.

Nakamura: The only thing that was on my mind was to figure out how to use them to improve characteristics, to be able to put it to commercial use.

Tanaka: So then, for the composition on the medium side in the trial experiments in your research, you must have tried floppy disks, tapes and hard disks later on. What types did you use for what purpose?

Nakamura: Well, to summarize, the basis were the auxiliary pole driven type single-magnetic-pole heads so we had to insert a medium between them. Since we had to insert a medium between the auxiliary pole and main pole, we needed to create a space that was about 100 microns. It is possible it could have been wider but we didn't have the capacity to focus on that. So we first used the tape and next we used the flexible disk type thin polyimide film with both sides sputtered for balance. We conducted experiments using those. I felt we started using it because it was easy to use in our experiments but the world wanted to put it to commercial use and things just started heading in that direction. At the end we struggled with the curling issue. Cobalt chromium is stiff. A stiff film, when there is film like this on plastic, not only does it cause curling but when dust adheres onto something it damages the head and created huge reliability issues. I sensed that too so I was skeptical but everyone was moving towards putting it into commercial use so we were pulled into that movement as well. So in the end, it didn't work. I think at around the end of the 80's it was determined that it was unreliable. Towards the end, many voiced this concern and many companies stopped the project so in 1989 we switched over to the hard disk and used the hard disk as a medium. We changed the head so that the structure would work with a hard disk. The auxiliary pole excitation wasn't working so we changed it so that excitation occurred on the main pole side. However, we didn't change the basic concept of exciting the fundamental main pole tip for auxiliary pole excitation and we had Mr. Watanabe, whom I mentioned earlier, create a head with a structure where excitation would occur on the main pole side and we used that for our experiments of the hard disk contact type.

Tanaka: So in other words, you were conducting experiments and research by testing basic structures of the hard disk drive that was currently in commercial use in 1989.

Nakamura: However, we couldn't do the flying head, we couldn't make something of that structure at our lab. Even if we were to get it made, the environment made that a little different to ask for. So, we went with the contact type, the structure was similar to a needle being placed on a record on a turntable, that was the kind of head we used for our experiments.

Tanaka: Professor, I believe you have the head that lightly touches you made back then right there with you.

Nakamura: Yes, I believe it is this one here. The structure was like this.
At that time the structure was made for it to be used using its own weight. I have a photograph here. It was a structure like this and Mr. Watanabe made all of this and the envelope was done very nicely, it turned out to be a really nice envelope. We were grateful we were able to conduct such great experiments.

It was suggested that we should pursue the contact type and I think even at relatively high speeds, it wouldn't have had any issues.

Tanaka: Other than the difference between contact and floating, the structure is virtually the same as the structure for commercial use currently being used.

Nakamura: Our experiments must have appeared to look risky from the outside.

Tanaka: So Professor, so could you tell us about how perpendicular magnetic recording was handled as a government project or as an industry-government academia collaboration, the course of events that took place and what kind of role it played?

Nakamura: Well, in the case of Japanese universities, scientific research subsidies are the basis for research. Of course, we receive public funds from the government so we received scientific research subsidies on top of that. Therefore prior to 1990, when Professor Iwasaki was with us, we received a portion of that, purchased equipment and conducted research. And I believe we may have received some funding from industry. However, in the early 90's, after Professor Iwasaki left, there were 3 to 4 years when we stopped receiving scientific research funds. But we had all the equipment we needed so I don't recall this time being extremely difficult. So then, in Japan there was a trend where people thought it might be better if it was an industry-academia collaboration, well, corporate people such as Mr. Hokkyo voiced such opinions and so we asked the government-related organizations for assistance but we were unable to come across anything worthwhile. However, around the late 90's we started to see some movement, one movement was called the SRC which was for the industry and universities to work together conducting joint research. Then there was ASET where I believe it was the Ministry of Economy, Trade and Industry, there was an arrangement to get a small grant from them. Finally, when it started to look like we had something we could use, we received huge donations from corporations. We also received support from the Japan Society for the Promotion of Science. In the end we received something called the RR2002 from the Ministry of Education, Culture, Sports, Science and Technology because IT, because the government felt that Japan was behind in IT and wanted to become a state-of-the-art IT nation so they were funding many different projects and one of them was for storage which turned out to be a significant amount of money so I think many corporations such as Toshiba and Hitachi jumped at the opportunity. Therefore, by then, we had all the equipment we needed and with the support from many corporations, I believe this gave us a huge momentum to push us towards commercialization. Of course, I think we were able to somewhat, I think we had the freedom to do things the way we wanted to. How about you Professor Muraoka?

Muraoka: Indeed we did. In that sense, industry-academia collaboration was very important, especially like the SRC, it placed emphasis on highly flexible voluntary activities, so SRC was very good, I think.

Tanaka: I see. Thank you very much. I think not only was the research on perpendicular magnetic recordings important, the research served to educate students and nurture human resources, so how do you feel about the role it played?

Nakamura: I think Professor Muraoka, who was onsite the most, who was closest to the students, may be able to share something with us.

Muraoka: Yes. Being able to work together with the students was a fun theme to explore. To be more specific what fun means, as Professor Nakamura mentioned earlier, our approach was focused on conducting experiments, we did some simulations as well but whatever the case, it was nice to be in a position where our data allowed us to always aim for the top in the world and Tohoku University was close to the top among all universities researching perpendicular recording so when we were able to get good data, it was data that was regarded as world class. I think we were all happy because all the students were working under such a theme. Students wouldn't be happy if they were somewhere where no matter what they did they couldn't even get close to being at the top. This kind of environment and, let's see, of course the fact that it was a novel idea would be the biggest reason, however, the environment was well prepared and we were able to create heads and disks on our own, it was an environment that allowed us to conduct our experiments with devices full of our ideas if we wanted to do so, the fact that we had that environment was really nice.

Tanaka: You welcomed many researchers from corporations. How many of them were there?

Muraoka: Uh, I think it was several dozen. Maybe around 80 people. I believe that was the count.

Nakamura: We welcomed people from various places, so many it was hard to keep count. And people from foreign countries, including from the U.S. and nearby countries such as China and South Korea. We also welcomed people from Europe, many different places such as from the U.K., France, the Netherlands and Germany. Some stayed long term, so in that respect students were aware they were conducting leading research, maybe it would be better if we described it as research for something useful, however, since they were researching something that can be useful immediately, we had many people visiting the lab to observe or work together with us so I believe they had plenty of opportunities to become friends with people from other countries as well. In that sense, I think our lab was a relatively easy, fun lab to work in if you wanted to work there. I'm not sure if I should call it fun... I think it was a lab that energized students. I can't say much more since I wasn't there for the most part towards the end. During the first half, I think we were very active for various reasons in the earlier stages of perpendicular recording research.

Tanaka: So I guess we could say in such a pragmatic environment there were a lot of collaborations in research with industry and foreign countries, would that be correct? So now I would like to ask about the contributions perpendicular recording research has made to society.
Right now, I think extensive research is being conducted on perpendicular recording so if you have any thoughts or expectations on future developments, especially in technology or recording density, could you share that with us?

Nakamura: I'll go first. To be honest, some time has passed since I stepped away from research so I have not been keeping up with current storage-related research. I do know that researchers are facing many challenges. So they are still in the development stages of what was created as perpendicular magnetic recordings so I am curious to know which direction they will go with the actual item. Such as implementing the shingled recording method. And there are many other things in the research stage. Regardless, I don't think the method to use perpendicular magnetization on the film surface will change. So in that sense, it may be better to call perpendicular magnetic recording the perpendicular magnetic method. I believe this will continue on. As for what will happen in future, I would like for Professor Muraoka to share that with us. Oh, but one thing that does concern me is, whatever the case, I think this applies to flash-related things and semiconductors as well but I feel they have reached their physical limits so I am interested to learn how they will prevail over these physical limitations and how technology will overcome these obstacles and I hope they will strive to go in that direction. In regards to the future, Professor Muraoka, please share your thoughts.

Tanaka: Let's ask Professor Muraoka, who is at the forefront of this research, about the future of the technological aspects of perpendicular recording.

Muraoka: This is a difficult question. That is because we went from perpendicular recording to longitudinal recording to perpendicular recording so I think we thought, obviously there could be a third recording option, however, we tried various methods and realized there is not. As Professor Nakamura mentioned now, I think we have things to do in the area of expansion using perpendicular recording. In that sense, MAMR and HAMR is making advancement. Well, there is also the BPM. So in this direction, this all uses perpendicular recording so in that sense, well, I think this is the way we are going. So in principle, it goes along with this but as far as technology goes, for example, I think there is the task of narrowing down knowledge for reliability.

Nakamura: Can I say something? This may not be necessary to say but even now we see snippets of technology that significantly increases recording density from time to time in press releases and such in newspapers, etc. These existed before but in the end they are meaningless unless the usability or the use itself can be incorporated into the technology used today. Generally, even if it is said that physically the recording density will increase, many say that it sounds impossible, it is impossible. So there has to be a clear distinction, we have to advance with consideration to whether this is technology that can really be used or else I have concerns that funding will be wasted. This is just a friendly word of advice.

Tanaka: I see. Thank you very much. So what you are saying is that basically enhancements should be made to expand the current perpendicular recording.

Nakamura: My fear is that, including usability, rather than recording density being this or that, when it is actually incorporated into a storage device, it has to go in the direction of improving usability, such as access time like now or else even if it is new technology, it would take a sufficient amount of time for development and could quite possibly go to waste.

Tanaka: Next, let's discuss technology for storage including perpendicular recording. I think this something being used in a very wide range of things and is becoming a driving force that could change society. Please share your thoughts on its diversity.

Nakamura: This would be Professor Muraoka's field so I can't say much about it. However, when I see all these different things such as artificial intelligence and all the latest technology, I believe that in all the technologies that we look forward to, storage is a fundamental technology. In short, new technology is being developed to collect data and to use them so I think we are creating the foundation. So I think the most important thing is to firmly build this base and be able to provide it as something easy to use. I feel I would like for future engineers to carry on with the strong spirit to bear the responsibility of creating the basis for future new technology Therefore, I strongly feel that storage is the foundation for all current technology.

Tanaka: Professor Muraoka, do you feel the same way too?

Muraoka: Absolutely. Well, so to speak, how should I put this, I think first of all, without storage as the foundation in all the technological fields for ICT technology, I believe that there has to be a way to store data and information and on top of that there should be various methods for information processing. So in this sense, it is the foundation. In the future, whether it be IoT, big data or AI, they are all headed in the direction where information will be flowing so I feel that storage will be very critical. It briefly crossed my mind that if the IDC data is for real, I think it was around 2007, there were statistics that showed that the amount of generated information exceeded the amount of accumulated information. And that gap will steadily widen. In other words, we live in a world where, regrettably, there is no longer any more space to store created information and the amount of information that cannot be stored will steadily increase. If this is the case, I believe that we will be entering an era where we have to put our heads together to come up with a way to handle this although this is not just in the case of magnetic recording technology. In this sense, one thing that is inevitable is that we will need something that can handle an enormous amount of information by gathering all different kinds of storage technology and organically combining them. For example, recently there was an article on DNA storage in IEEE Spectrum so maybe the archives can be stored in that manner. Or perhaps it can be made better using that flash memory or perhaps something else like MRAM, which is sure to come out soon. On the other hand, when considering bit costs, without the disk, there is no other technology to store this much information other than magnetically. Therefore, since perpendicular recording has already made this achievement, this will be continued to be used in future. Meanwhile, new technology will be introduced organically into the storage family so if they are not used to processing this enormous amount of information, if it turns out that information is being tossed away and important information cannot be kept at hand, I think that would be problematic.

Tanaka: I see. Thank you very much. Last but not least, I would like for you to send a message to the next-generation researchers, especially the storage researchers. Let’s start with Professor Muraoka.

Muraoka: Well, let me see. I would like to say, how should I put it, that there will be many people taking the initiative in an era full of opportunities so they are in a lucky environment. As I just said, there are plenty of opportunities so I would like for everyone to work with the understanding that with the knowledge as a researcher, there are many options to open up the door to the future.

Tanaka: Professor Nakamura, your message please.

Nakamura: It’s hard to say this to young people but... Especially now, everything is specialized and I feel even storage is extremely subdivided. So I understand that it is a pretty difficult field. It is not like, for example, back in the day, we were able to research everything for perpendicular recording from heads to media and even systems and I know that in the environment now it is becoming increasingly difficult to do something so I can’t quite say this is what they should do. However, well, I may get in trouble for saying this but research was my favorite pastime. Someone who really enjoyed doing what they did, did what they wanted to do and advanced the world. However, nowadays, business is involved which makes things very complicated. Nevertheless, I want researchers to have tenacity in the research they believe in and I want them to enjoy doing it. So, there’s nothing wrong with focusing on one matter and to obsess over it but, how should I put it, I would really appreciate it if they could look to the side, take a look around and use their knowledge to advance their research as well as be able to create some kind of fun in all of it and enjoy the research they are doing. If the environment allows this, that is. Additionally, we thought storage technology was based on hardware technology but as Mr. Muraoka just mentioned, it is software technology, I guess it would commonly be called software technology and if it can't be linked to such technology, it will be difficult for it to make any further advancements, so with that in mind, I would like for everyone to move forward with consideration to the best way to advance this technology. By doing so, I believe this will open their eyes to the world outside magnetics. This is about all I can think of to say.

Tanaka: Thank you very much. I asked many questions during this interview and I would like to thank you for your responses and explanations. I believe what you have shared with us today will be helpful to generations to follow. Thank you very much for joining us today.

Nakamura: Thank you very much.

Muraoka: Thank you very much.
END OF THE INTERVIEW

