Oral History of TMR Head Panel
(Naoki Watanabe, Hiroki Maehara, Koichi Terunuma and Chang Man Park)

Interviewed by:
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Chris Bajorek: Well, this interview centers on the development of the MgO tunnel barrier used in modern TMR heads. Hard disk drives have survived as the information storage density device of choice because of sustained and steep advances in storage density. Density advances required downward scaling of key components. The reduction of the size of stored bits caused signal amplitude reduction which necessitated the invention of more powerful detectors. Magnetoresistive heads were the successful answer. The third generation of MR heads introduced the phenomenon of tunneling to increase the change of resistance. The largest change of TMR head resistance has been achieved with the MgO tunnel barrier. This oral history records a history of the development of the polycrystalline MgO based magnetic tunnel junction and the contributions to its success by Messrs. Naoki Watanabe, Hiroki Maehara, Koichi Terunuma and Chang Man Park. Now, we'll turn over to the questions.

We'll start with you Naoki, could you tell us a bit about your background your name, background, where were you born and where did you grow up, some of the schools you went to? Please go ahead.

Naoki Watanabe: I'm Naoki Watanabe. I was born in Japan, Yamanashi Prefecture, where I grew up during high school. Then I went to the Yokohama National University studying metallurgy. In childhood I'm a kind of-- I liked architecture, but I went into materials science in the university. That's kind of my story.

Bajorek: Good. So Hiroki, would you like to go ahead next and give us your background?

Hiroki Maehara: Okay. I am Hiroki Maehara. I was born in Tokyo, Japan and grew up there. And I graduated from Tokyo Denki University where I was researching for the electrical circuit. I joined the Canon Anelva in 2002. After I joined Canon Anelva I researched the deposition process for the magnetic materials. And now I'm researching for the spintronics devices such as magnetic sensors or the MRAM. Thank you.

Bajorek: And is that continuing at Canon Anelva? Or did you move to different employer?

Maehare: I moved to Tokyo Electron in 2014.

Bajorek: How about you Chang Man?

Chang Man Park: I'm Chang Man Park. I born in Korea, South Korea, of course. And there I finished my Ph.D. The major was physics. When I was in my thirties I moved to the U.S. My government supported a two-year post doc program so that I joined the materials science department in Stanford University. And then I learned most of the state of art technology related with the magnetic thin film and vacuum science and all of those things. After that I joined the HDD industry, the year 2001, and worked all the way in the magnetic recording head sensor area. So that's today - is the topic of the MgO sensor and MTJ sensor. Then I moved to Samsung for spintronics MRAM, STT-MRAM area. Then in the year 2013 I joined Tokyo Electron Company. And I'm working for the STT-MRAM which is, again, related with the MgO MTJ technology for spintronics.

Bajorek: And your first job in the industry was with TDK?

Park: It was at Read-Rite in Fremont, California, recording head manufacturing company. And I was working on the TMR at that time, my first job.

Bajorek: And Terunuma-san, a little bit about your background.

Koichi Terunuma: My name is Koichi Terunuma. I graduated from Ibaraki University. And also grew up in Ibaraki Prefecture. I graduated in 1983 and joined TDK. At first my mission was development of high BS high flux magnetization, soft film materials for head by sputtering. Next, I joined the head division and development of read reader and writer for advanced magnetic head. That's all. Thank you.

Bajorek: Thank you. And I think Watanabe-san you went directly Anelva after the university? Or did you work for other companies?

Watanabe: No. I worked for Anelva since joining in 1985. And then working for the equipment development for the sputtering, mainly for magnetic optical disk, optical and hard disk equipment. And so the hard disk media and the head for today's subject for MgO fabrication tools. Then after the development in Anelva I moved to Tokyo Electron to make another PVD tool development thing. Now, also, I'm still working for MgO process development right now. It's my life's work kind of. Yeah.

Bajorek: It's very important development. Right?

Watanabe: Yeah.

Bajorek: Could you tell us a little bit more about your current position at Tokyo Electron?

Watanabe: Yeah, I'm a project leader of advanced film project. So it is almost mainly for MRAM application, PVD tools. Then such multilayer it's a very common use, so very complicated multilayer like a tunnel junction. So we are now developed also tool equipment itself also process…

Bajorek: Fabrication for the deposition.

Watanabe: Yeah.

Bajorek: I'd like to explore a little bit more everybody else's current position. But before we go there, if you think back, were there some people who had a major influence on your thinking about which field to study, what area to focus on?

Watanabe: After join the company, some company?

Bajorek: Or even in the university. Were there any particular professors?

Watanabe: Yeah. So most of the influence person is Sasaki-san from Showa Denko. So when I joined Anelva in the-- now the Showa Denko is the biggest media company for hard drive. But at that time it was nothing. So then Sasaki-san was starting, well the business for media. So I'm working very closely. So I learned from him many things, how to make it. He may be the most effective person over all in this industry.

Bajorek: Yeah, he seems to be a very strong leader.

Watanabe: Yeah, you know.

Bajorek: Yeah. Terunuma-san, a little bit about your current position and any people who had a major influence.

Terunuma: Current position is spin applied device application group. I'm a group leader now. I was influenced by the professor at the university. His name is Furukoshi. Already passed away. He's a very-- gave many influences.

Bajorek: Thank you. How about yourselves? Current position.

Maehara: My current position is researcher and researching for the deposition process and etching process for the MTJ or some magnetic materials. And my first boss was Naoki Watanabe and I was influenced from him for the engineering. And I was collaborating with Professor Suzuki who works in the Osaka University. And he taught me about the scientific thinking and the researching method for me. And I'm very thankful for him and Watanabe-san.

Bajorek: It's nice to have you both together.

<group laughter>

Bajorek: And Chang Man.

Park: Many people.

<group laughter>

Park: I cannot thank enough to all of those people. But if I come up with maybe one or two, then my advisor from Korea who taught me and who started me on magnetics. So his name is Togun Hang. But he's not doing magnetics anymore. He's transitioned to the bio. So maybe he got enough magnetics.

<group laughter>

Park: And then second important in my research or engineering life was Bob White from Stanford. Every morning at six thirty he showed up in my lab. And he greeted and kind of encouraged my research when we worked together in Stanford. He gave me a lot of opportunity as a scientist at the time. And I could go anywhere in Stanford Lab per his, you know, support and help. So not only the magnetics but at the time I learned e-beam nanolithography, all those things. So now that knowledge is very useful day by day of my technical marketing, my current job. So I wish I can meet him again. But he's pretty old enough right now. He's retired. So those two gentlemen and scientists had the biggest impact on my career and life. Not only science, by life. Yeah, I learned a lot from those two mainly.

Bajorek: And if he came to the lab at six thirty in the morning, when did you have to be there? Or you just didn't go home at night?

<group laughter>

Park: Yeah. It was too much fun because compared to my Ph.D. time of research in Korea compared to in Stanford, Stanford at the time was already very advanced in everything. So all of the things I looked at in the technical journals were available in front of me. So that was a kind of a big toy store for me. I enjoyed that a lot. Yeah.

Bajorek: And your current positon is in marketing for…

Park: Yeah. Director of Technical Marketing, belong to Tokyo Electron Corporate. But, again, my major was in magnetics and also spent time for read head sensor so that I move around promoting this STT-MRAM technology with the PVD product. So, again, Watanabe-san and I visiting many, many other magnetics colleagues who are working on the semiconductor memory for STT-MRAM. So every day is kind of a happy day. A lot of challenges but still good.

Bajorek: Sounds like it was a very interesting experience. So maybe we could move to how did the interest in MgO and MTJ start. Maybe Watanabe-san, you can start that. How did you-- I think the development happened while you were at Anelva, Canon Anelva. So how did that start? Why were you and why was Anelva interested in this subject?

Watanabe: Most of my work in the '90s was for media for the hard disk drive and for media tools. So we -- also at that time -- I was thinking for the head, the head was also weak, needing a big challenge for the high SNR or the high output for signal. So then at that time also MRAM becoming hot as of 2000 or around the year 2000. So the very big requirement needs from a customer for the TMR head and the GMR head to transition to the TMR. Also MRAM is using TMR MTJ. So I was very interested in these opportunities. Then TMR since -- but GMR is at that time almost ten percent MR ratio. But TMR has the potential to over fifty percent kind of. So we just were very interested in that, to improve the MR ratio. So in early 2000 to 2004 so struggling for alumina. So maybe all researcher working for alumina TMR. Then few percent improved the limitation for almost seventeen percent for TMR ratio. But at that time maybe customers and also industry needed higher MR ratio. So at that time, so Yuasa-san from AIST was working on MgO, and also at Alabama University Dr. Butler predicted over 1000 percent for the MR ratio for the potential for MgO. So everyone very excited for 1000 percent MR, is it possible or not? So everyone working, the researchers working. So also I'm working. So at that that time Yuasa-san shows over 200 percent for single crystal MgO. Then oh that's possible for over 100 percent is something very surprising, 100 percent over. And then take 200 percent. So that's very interesting and exciting. At that time, I'm working for -- Yuasa-san's technique is very high temperature for the single crystal deposition. Industry doesn't like such difficult process for the tough high temperature process. So then we were thinking how to make it to the industry's, how to contribute to the existing, at that time existing products. And then at that time, Maehara-san was working for AIST. So we thought we order one closer to the industry like process. So and he's working for, like developed a new cobalt iron boron amorphous process. It's room temperature. It's nothing to changing existing process. So cobalt iron boron - MgO - cobalt iron boron sandwiches. So it's very unique. And then we published the paper. Then all of our customers were interested that over 230 percent MR ratio was achieved. Then oh, so it's almost the entire industry very excited. It's -- so over alumina 17 percent for TMR head. It's four times jumping to 70%. So maybe -- so this jump is very good for the hard disk recording density improvement. So I thought it's just a big opportunity like Butler-san presented 1000 percent. Yuasa-san presented 200 percent single crystal potential. So my thinking is how to contribute to industry? So it's a very good opportunity, such kind of very exciting time.

Bajorek: The work you did Maehara-san in the university was on the single crystal, it was amorphous electrodes but still single crystal MgO? Or was it polycrystalline in the MgO?

Maehare: Okay. First, we tried to make the single crystal iron – MgO - iron system by the PVD. But it's difficult to make for the industrial system. So we tried to change thinking. And we discovered MgO grows on the -- as a polycrystal on the amorphous cobalt iron boron. But we needed an epitaxial relationship between the magnetic materials and the MgO for obtaining the huge MR ratio. We discovered such a phenomenon but not enough for obtaining the huge MR ratio. So we developed a combined deposition process and annealing process. We called the annealing process solid phase epitaxial process. And it was successful to obtain the huge MR ratio, over the 200 percent. And it was very suitable for our industry's technology.

Bajorek: Very interesting. So how did it evolve from that point? You have the exciting results in the university. You're interested in solving the industry's problem. How did it evolve from that point onward? You just hired Maehara?

<group laughter>

Watanabe: No. But the idea is, ideally for the cobalt iron boron as existed. Most surprisingly, cobalt iron boron is amorphous. We checked the published paper says MgO is a crystal, a single crystal on the amorphous film. So self-crystal-- a single crystalized MgO. And that I'm very surprised. Why? Why MgO itself makes a single crystal on the amorphous? Usually it needs the texturing before MgO deposition for the single crystal iron or other material. But amorphous on the MgO is very surprising. So no one maybe understood that at that time. I also cannot understand why MgO is a single crystal. So that is very funny now. But Maehara-san made those kinds of films.

Bajorek: But then you apparently were able to refine the process until you made one that you thought would be satisfactory for the industry.

Watanabe: How you mean?

Bajorek: I'm trying to bridge from the early work and the exciting results to how did the process design of the MTJ migrate to the head companies?

Watanabe: At that time we needed to publish the paper first, to have the data read by every researcher, or also maybe customer want-- let them know. So as early as possible, so we make the paper thing. That's maybe very easy to make a customer side, so I think. So I very quickly made papers.

Bajorek: You Chang Man and you Koichi were in the receiving end of this in the head companies. How do you see it from your perspective? How did the MgO knowhow migrate into practical heads? Did it come indirectly to you? Or did it come from Anelva? I'm just trying to figure out how the process final design made it.

Terunuma: Yes, Anelva informed us that MgO shows very high MR ratio. And we also understood it. But the resistivity is so high at that time, double digit. For head applications, single digit is necessary. But soon resistivity was reduced to single digit, and also showed high MR ratio. And TDK decided to prepare the extra head by using MgO. So we asked Anelva for the test deposition. The result is so promising that output signal is three times, or much more than three times larger than aluminum oxide MTJ. TDK presented at TMRC year 2005 the first report of MgO reader. But - the output signal was so high - but also showed very high noise, Barkhausen noise, random telegraph noise and so on. So we started tuning our stack configuration, such as layer composition or layer configuration, to reduce noise. For example, the magnetostriction of the free layer. First MgOs used the cobalt iron boron switching layers. But we tuned the three-layer composition and three-layer configuration to reduce noise. And also we already had the knowhow of a three-layer configuration for the aluminum oxide MTJ. At that time, it was not so difficult to tune up, so we succeeded in making MgO MTJs and shipped heads for our customers in the year 2007.

Bajorek: Could it be that TDK's TMR with MgO was a first head in the industry?

Terunuma: Our understanding is so.

Bajorek: Okay. And Chang Man, where were you at this point in time remind us? Were you at Read-Rite?

Park: No. At that time, I was at Western Digital, 2003, '04, '05. So that was the peak time of the MgO development. And, of course, we were competing with Terunuma-san for MgO development. Everybody was surprised from this technical journal published by Anelva and Yuasa-san jointly because the TMR ratio was amazingly high. But, again, like Terunuma-san described, in the read head version it is not only signal but also noise we need to control. Then they were silently engineering in their shop, in R&D shop. So everybody was very quiet but whenever we go to international magnetic conference then every topic was MgO-related because everybody was enjoying this high signal in MgO technology at that time. So we were very--somewhat afraid because it was too amazing. But on the other hand, we were very confident that this would be the next generation read head technology. So we were enjoying at the time, as an engineer and researcher, this MgO kind of innovation at that time.

Bajorek: I want to just clarify, pin down some of the numbers. I think you said Watanabe-san that the maximum resistance change for the alumina TMR was about seventeen percent. One seven, right?

Watanabe: Yeah, one seven.

Bajorek: And the early MgO TMR heads had four times…

Watanabe: Yeah. Yeah.

Bajorek: And what was the main breakthrough that enabled the reduction of the resistance? Was that modifying the stack by adding an Mg layer under the MgO layer? What reduced that resistance?

Maehare: MgO thickness, because MTJ resistance depends on the tunneling barrier thickness. So we must reduce the MgO thickness.

Bajorek: Was that the only main mechanism? Because I remember reading some of the papers on the stacks, the MgO junctions-- I mean the MTJ junctions. And it looked like in addition to having magnetic electrode one also deposited metallic magnesium layer and then the MgO. And what was that extra Mg layer for? Do you remember? I mean I thought perhaps that was also for impedance control.

Terunuma: In the TDK case we used natural oxidation, Mg metal oxidation. And also the aluminum oxide MTJ also used natural oxidation. Plasma oxidation is so strong.

Bajorek: Very good. And so the first heads shipped in 2007. And then how quickly did the industry switch to MgO.

Terunuma: Yeah, so quick.

Bajorek: Do you remember? You were at WD and it also happened quickly?

Park: Hitachi GST. 2005 I moved to Hitachi GST. So it was in the boundary of this MgO introduction as production. I think in 2007 most head manufacturing companies or HDD companies started producing this MgO read head. Because it was a huge competition because not only the SNR improvement but also other, such as the following yield improvement, and it was kind of a free gift. So that every HDD head manufacturing company started making production around 2007 and ’08. Yeah, something like that. It was so quick.

Bajorek: Nobody could afford to miss it. Right? It was so important.

Watanabe: HDD, as I mentioned, industry itself is very dynamic, very - as Chris-san knows. And new technology is published and very, very quickly used in the existing product for the hard drive. So it's -- I know the semiconductor, semiconductor business and also other, the flat panel. But most dynamic industry is hard drive. Very, very quickly changing for the new technology, introduction. Maybe, as Park-san says it's almost one year, I don't know, but very quickly changing all of the parts.

Bajorek: It may have been one of the fastest transitions in the industry. It sounds like it was about in one year we switched from aluminum oxide to MgO.

Watanabe: Yeah.

Bajorek: You all talked a little bit about the interaction between the university and industry. This may be a key example of the value of that kind of collaboration. Right? Can you talk a little bit about AIST some more? Was it strictly focused on magnetics? Or other subjects too?

Watanabe: AIST, so Yuasa-san, professor Yuasa's group is focusing on spintronics, not only for hard drive and for MRAM application development. Very early stage, 2000, around then. So we were at that time, so many papers we were working in collaboration with AIST and the Anelva. Then that also Maehara-san was involved. So Yuasa-san's thinking and also Suzuki-sensei's from Osaka University, Suzuki-sensei who is also part of the AIST. And his idea and image is very close to the industrial mind. So how to support, how to contribute to industry for hard drive MR. So that's very good for the working with the AIST. Some professor, like university professor, is far away from the existing products. But Yuasa-san's group and Suzuki-sensei are very close to the industry. So we, I think, at that time we were working with the AIST. So very good synergy, good collaboration, I think.

Bajorek: I think it's an exceptional case because I know of many joint university industry efforts that try to achieve such success but I know it's very difficult. So it's very positive that AIST was able to contribute like this and help make this happen. Let's see. I think we covered most of the ground. Any opinions about the outlook for the future of MgO? Or are we going to have to invent a new tunnel barrier? What do you think?

Watanabe: Yeah, I personally spent almost ten years for MgO so in the industry is mainly still focusing on MgO, not only the hard drive but for the MRAM MgO barriers. So it's currently it's no choice. It's a very industry friendly process for MgO application right now I believe. So as also a material not only MgO but everyone researcher working. But there is no better choice, I think, right now. And then the future also MRAM coming in case is that only MgO right now. And the MgO barrier is still mainstream for the future for the tunnel junctions, I think.

Bajorek: Looks like a very good solid invention discovery. And no one has yet invented anything that that will be superior.

Watanabe: Yeah. How do you think?

Park: True. MgO is kind of gift for this research area and also industry. So I'm now working for HDD industry and semiconductor industry and also non-semiconductor industry, these three areas. Right now, everybody is talking about we are hitting the Moore's Law, the wall of Moore's Law. So you cannot pack many more transistors. We are hitting a kind of technology wall in semiconductors. So a lot of people started thinking in different areas, directions like spintronics. But this spintronics already started from the HDD industry a long time ago. But when MgO came it stimulated more variety of the application and interest and phenomena in magnetics and spintronics. Then, now, semiconductor people started adapting it. That is STT-MRAM and also beyond STT-MRAM, which is very, very promising. I mean the year 2000 a lot industry and company players start MRAM. But at the time it was in-plane type of toggle or field generating MRAM. But now almost everybody started using MgO tunnel junction for their STT-MRAM. And then not only semiconductor STT-MRAM but also the automotive sensor and also HDD side still shrinking and trying to make it smaller and lower. So this MgO is kind of a gift for all of the researchers in this entire industry. And without knowing it maybe there's a many, many MgO MTJs around us already. One thing is so far there's no new material which is very industry friendly and also fundamentally strong enough to spintronics. There's no replacing material rather than MgO, magnesium oxide, yet so far. So maybe I cannot say the exact number but maybe another ten-year like we went through, MgO can be popular and used as the main technology core. So I think.

Bajorek: I hope you're right. I hope it sounds like it has the potential to have a very bright future. Anything else that we should cover before we end the interview? Any other subject that you'd like to discuss?

Terunuma: No.

Bajorek: Well, I want to thank you very much for giving us the opportunity to interview you about this important development, the importance of MgO and it's doubly good to know that it may have potential to penetrate a variety of technologies not just TMR heads. Thank you very much.

All Interviewees: Thank you. Thank you very much.

END OF THE INTERVIEW

