The Role of Universities in the Development of Hard Disk Drives

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Hard disk drives (HDDs) represent a remarkable technology. The storage capacity, performance, size and affordability of HDDs have improved dramatically since the first commercial drive, the RAMAC, was introduced by IBM in 1956. The RAMAC had a storage capacity of 5 M Bytes (MB) and consisted of fifty 24 inch disks. The rental price for 1 MB of storage was $130/month (1). Today one can purchase a 3.5 inch drive for a desktop PC with a capacity of 2TB for well under $200. An often used measure of this improvement is the increase in areal density over time. The RAMAC had a storage density of 2 kbits/in\(^2\); whereas the storage density of high-end drives now exceeds 500 Gbits/in\(^2\). HDD storage densities have increased nearly exponentially in time. Much of this increase has been a result of engineering developments that have allowed a scaling down of all relevant dimensions. However, this growth would not have been sustained without new technologies that were based on discoveries resulting from basic research, much of which has been done at universities throughout the world.

One of the main reasons for the continued increase in storage densities has been the development of read heads with increasing sensitivity, allowing the detection of ever smaller bits. One of the most notable contributions to this development was the discovery of Giant Magnetoresistance (GMR) in 1988 by Abert Fert at the University of Paris-Sud (2) and Peter Grünberg at Julich Research Center (3), for which they received the Nobel Prize in 2007. GMR read heads were first introduced in hard drives in 1997 as a replacement for MR heads and allowed the detection of ever smaller bits. Heads based on Tunneling Magnetoresistance (TMR) began to replace GMR heads in 2005. TMR was discovered by Jullière at the University of Rennes in France (4). The original effect was observed in Fe/Ge-O/Co at 4.2 K but was very small at room temperature. Research done by Miyazaki at the University of Tohoku (5), Moodera at MIT (6), and others led to the development of TMR stacks with amorphous Al\(_2\)O\(_3\) tunnel barriers with high room temperature sensitivity which was used in the first TMR heads. Current TMR read heads now make use of crystalline MgO as the tunnel barrier, which greatly enhances the magnetoresistance. Enhanced TMR using MgO was predicted theoretically by Butler at Oak Ridge National Laboratory (now at the University of Alabama (7)) and Mathon at City University in London (8).

University researchers have also played an important role in the development of new magnetic media. Conventional media have a granular structure with tens of grains making up a single bit. Decreasing bit sizes have required media with deceasing grain sizes. Grain sizes in current media consisting of CoPt-based alloys are smaller than 10 nm and are rapidly approaching the superparamagnetic (SP) limit. In order to delay the SP limit, materials with higher magneto-crystalline anisotropy energy (MAE) must be employed. For grains with uniform anisotropy which reverse coherently, higher MAE means that higher write fields are required, but this is limited by the saturation magnetization of the head. Beginning in 2005, the HDD industry made a rapid transition from longitudinal to perpendicular recording (PMR). One of the main advantages of PMR was that it allowed a head configuration giving a larger write field. PMR is attributed to work originally done in 1976 by Iwasaki at Tohoku University (9). Recent work done by Victora at the University of Minnesota (10) and Suess at Vienna University of Technology (11) has shown that magnetic media with appropriately designed MAE gradients can have a reduced switching field to thermal stability ratio. Appropriately graded media can further extend the SP limit. Other technologies that are under consideration for extending the SP limit include bit patterned media (for increasing the ‘grain’ size) and heat assisted magnetic recording (for reducing the required write field).

FePt is a prime candidate high anisotropy material for new media. In the ordered \(L1_0\) phase, its anisotropy is approximately 10 times that of the CoPt-based alloys. Shouheng Sun (then at IBM and now at Brown University) demonstrated that FePt nanoparticles with narrow size distribution could be chemically synthesized and could self-assemble into highly ordered arrays (12). This led to great interest in chemically synthesized nanoparticles as potential new media. Subsequent research, much of which was done at universities, has shown that fabricating media using chemical synthesis is extremely challenging, and more attention is now directed at fabricating FePt media using sputter deposition. As an example, I note some of the work done on FePt at the University of Alabama. Butler and Chepulski showed theoretically that
FePt nanoparticles cannot be fully ordered and the maximum order parameter decreases with decreasing particle size\(^{10}\). Thompson, Nikles, and I demonstrated that certain metal additives can significantly reduce the ordering temperature, but enhance sintered grain growth. We also showed that nanoparticles, although uniform in size, can have a considerable compositional and anisotropy distribution\(^{10}\). These findings are also relevant to sputtered granular FePt films. One of the challenges with sputtered FePt films is limiting grain growth while thermally annealing the films to obtain the ordered phase. Yuki Inaba, working with Thompson and myself, recently studied the effect of pulse laser processing on chemical ordering and grain growth of FePt films\(^{11}\). The study demonstrated that chemical ordering can be obtained in the millisecond regime and that, compared with conventional annealing, grain growth during ordering is reduced. (Inaba is currently working at Fuji Electric on HDDs.)

Clearly, universities have played a significant role in HDD development and will continue to do so in the future. University-industry interactions are critical in this effort and their research can be complementary. Universities are not structured for short-term research. Much of the university research is done with and by graduate students whose dissertation projects typically takes several years. Industry, on the other hand, is motivated by market concerns and has the resources for rapid product development. In order to promote university-industry interactions, several university research centers related to magnetic recording have been established in the US during the past few decades. These include the Data Storage Systems Center (DSSC) at Carnegie Mellon University, the Center for Magnetic Recording Research (CMRR) at UC San Diego, the Center for Micromagnetics and Information Technologies (MINT) at the University of Minnesota, and the Center for Materials for Information Technology (MINT) at the University of Alabama, as well as several other centers. The larger centers typically have industrial sponsors which provide financial support for research and provide guidance on technologically relevant problems. In return, the centers hold annual and bi-annual reviews during which the research results are presented. Some centers also host industry scientists and engineers for extended periods of time and sponsor topical workshops for industry. One of the important roles played by universities is training of graduate students and postdoctoral fellows for employment by industry. At the MINT Center at the University of Alabama, the majority of graduate students and postdocs go into the information storage industry. Some of these students hold internships in industry during part of their graduate study.

The great New York Yankees baseball catcher Yogi Berra is famously quoted as saying “It’s tough to make predictions, especially about the future.” Likewise, no one really knows the future of magnetic recording. What we do know, however, is that it will be unlike the past since exponential growth cannot be indefinitely sustained. It should be a challenging and exciting adventure in which universities are expected to play a critical role.

**References**

(1) http://www.magneticdiskheritagecenter.org/MDHC/ RAMACBrochure.pdf


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