Hitachi's Overseas Research on Hard Disk Drive

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OVERVIEW: The magnetic HDD is now 50 years old, but demand is still growing for larger capacities, faster performance and enhanced features. The recording density for data on the surface of the disk has increased 60,000,000-fold in those 50 years and placed tremendous challenges on all aspects of the drive design. To continue this great progress and meet future demands, significant scientific and technological breakthroughs will be required over the next several years. The leaders in this industry will need to have the support from leading-edge research teams. In Hitachi, HDD-related research is performed in several overseas laboratories, in addition to the corporate research labs in Japan. The largest of the overseas research groups, the San Jose Research Center, located in San Jose Calif., USA, has a long history of contributions to HDD technology, including the invention of the HDD over 50 years ago. All these research activities are coordinated worldwide to leverage the unique skills and capabilities that exist globally in the Hitachi Group.

INTRODUCTION

THERE is an ever-growing demand for storing digital data on HDDs (hard disk drives). In 2005, over 380 million HDD units were shipped worldwide, driven in part by an expanding usage of hard disk drives in new applications, in particular consumer electronic devices. The DVR (digital video recorder) application is creating demand for HDDs with several terabytes (1,000 Gbytes) of capacity. This demand drives the need for new improvements to enable higher data densities and larger capacities at lower cost. Also, the broadening usage and value of digital data storage are creating demand for new features and capabilities, such as data encryption to provide more security in case of theft, expanded operating temperature range for automotive applications, and reliability and lifetimes consistent with home consumer devices, as opposed to notebook PC. Providing leading-edge solutions to these expanding requirements can only be achieved through long-term investments in research and development.

GLOBAL HDD RESEARCH ACTIVITIES

The storage business in Hitachi Group is vertically integrated and ranges from developing and manufacturing HDD components all the way up to complete storage system solutions. Hitachi Global Storage Technologies, Inc. (Hitachi GST) offers the broadest product portfolio of HDDs for every application today covering from enterprise servers to consumer electronics, including portable audio/video devices. RAID (redundant array of independent disks) System Division of Hitachi, Ltd. and Hitachi Data Systems Corporation are also major participants in the storage solution business.

Six Hitachi corporate laboratories and three overseas research laboratories have been contributing to technology development for the Hitachi HDD business.

Fig.1 shows the global scope of the HDD research work by geography. The San Jose Research Center (SJRC) of Hitachi GST and Hitachi Storage Mechanics Laboratory (HSTM) are focused primarily on developing HDD technologies. The research at SJRC spans a broad range of subjects from HDD technologies to new future storage technologies. HSTM, located in Singapore, was established in August 2005 in the R&D division of Hitachi Asia Ltd. and studies mechanics and head disk interface technologies. Hitachi Cambridge Laboratory (HCL), located in Cambridge, U.K., is one of the research laboratories in Hitachi Europe Ltd. and is studying spintronics devices for future storage applications. All the research activities among these three overseas labs

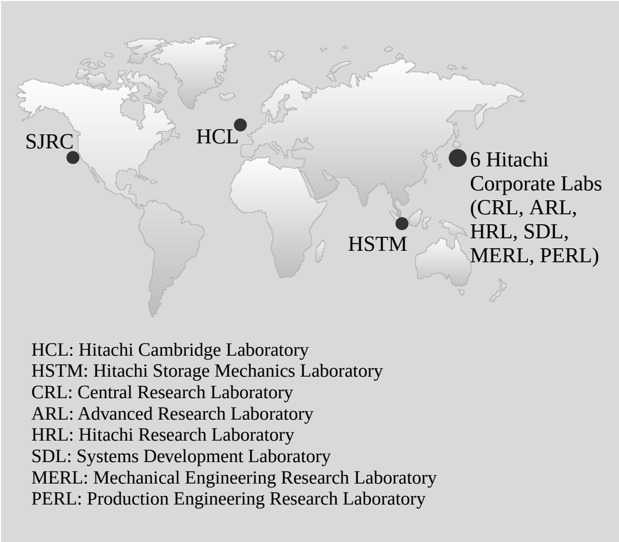

Fig. 1—Global Scope of Hitachi HDD (hard disk drive) Research Activities.
Worldwide scope of Hitachi HDD (hard disk drive) research activities. The San Jose Research Center (SJRC) is the main overseas research laboratory focused primarily on HDD-related technologies. The research activities in the overseas laboratories are being performed in close global collaboration with the six Hitachi corporate laboratories in Japan.

Fig. 2—First Hard Disk Drive with 24" Diameter Disks Compared with Modern 2.5" HDD.
The first HDD was introduced in 1956 with 50 disks of 24" diameter holding a total of 4.4 Mbytes of data. The purchase price of this HDD was $10,000,000 per Gbyte. For comparison in the foreground a modern HDD is shown holding 160 Gbyte of data on two 2.5" diameter disks at a purchase price of less than $1 per Gbyte.

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HISTORY OF HDD

In 2006, the HDD industry will celebrate the 50th anniversary of the first HDD. In September 1956, International Business Machines Corp. (IBM) introduced the 305 RAMAC* (random access method of accounting and control) computer system with the world's first magnetic hard disk for data storage (see Fig. 2). The refrigerator-size product offered unprecedented performance by permitting random access to a total storage capacity of 4.4 Mbytes distributed over 50 doubled-sided, two-foot-diameter disks. This first hard disk product stored data at a density of 2,000 bits of data per square inch and had a purchase price of $10,000,000 per Gbyte. By comparison, a modern 2.5 drive, e.g. used in notebook PCs, is about the size of a deck of cards, has a capacity of 160 Gbytes, stores data at 131 billion bits per square inch, and has a purchase price of less than $1 per gigabyte.

The most significant factor that has led to this tremendous advancement is the ability to increase the density at which data is stored on the surface of the disk, referred to as the areal density, by nearly eight orders of magnitude. This increase has driven major reductions in cost per bit, size, weight, power requirements, and fantastic increases in capacities. These advances led to the evolution of the HDD in terms of its size and shape, referred to as form factor, and in terms of standardizing its physical and electrical interfaces to the host system [e.g. ATA (advanced technology attachment interface and SCSI (small computer system interface)]. As the technical capabilities of the HDD expanded, so did their range of applications, and hence, the impact that the HDD has had on the evolution of computing systems from mainframes to PCs. The HDD is also playing a key role in emerging digital entertainment systems and portable consumer devices.

HISTORY OF SAN JOSE RESEARCH CENTER

The research center in San Jose dates back to 1952 when IBM established its first west coast R&D lab in downtown San Jose, California. In a few short years, the research team working there developed and shipped the first HDD product in 1956. At that time, the research lab moved to the new site in south San Jose that was established to manufacture this new product, and the research team remained there until 1986. In 1986 the research team, which had expanded over

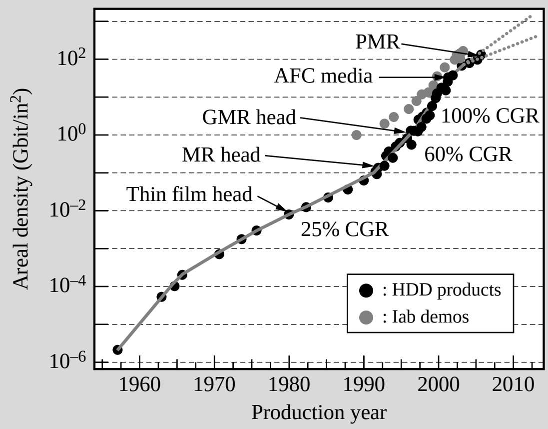
* RAMAC is a registered trademark of International Business Machines Corp.

those 30 years to include research into many other fields beside HDD, moved into a dedicated research facility in the hills overlooking the Almaden Valley in south San Jose. With the formation of the new company, Hitachi GST, from the merger of Hitachi's and IBM's HDD businesses, 129 employees from the former IBM research team transferred to create the SJRC of Hitachi GST. In 2006, the San Jose Research Center will move into a new state-of-the-art facility in the foothills of the Evergreen area of San Jose.

While over the last 50 years business needs have dictated that the SJRC move to a number of different physical locations, invariably it has been at the forefront of magnetic data storage research and its researchers some of the most respected in the industry. Today the SJRC is comprised of about 125 researchers working in a wide range of technical disciplines, including deposition, processing, and characterization of magnetic thin films, micro-magnetic theory and modeling, chemistry, signal processing, high-frequency electronic design, tribology, servo control, mechanical analysis and design, fluid dynamics, security algorithms, audio-visual middleware and software, and support for manufacturing process control and testing. Research projects at SJRC range from short term support for manufacturing yield issues, to strategic development of HDD technologies targeted for shipment in 3 to 5 years, to very long term thinking about future storage technologies, including 3D solid state storage devices. The research team, in addition to developing many breakthrough HDD technologies, including the thin film head, the MR (magnetoresistive) head, the GMR (giant MR) head and AFC (anti-ferromagnetically coupled) media, is also a major contributor to Hitachi GST's patent portfolio, which is the largest in the industry. In addition, the team publishes its research findings in some of the most prestigious scientific journals and participates in numerous, collaborative research projects with university groups around the world.

TECHNICAL PROGRESS

As shown in Fig.3, for the first 35 years the areal density of HDD products increased at an annual CGR (compound growth rate) of about 25%. However, starting in 1991 a number of technological advances led to an acceleration of this rate to about 60% and towards the end of the decade to an even greater rate of 100% (i.e. doubling every year). Starting in 2002, maintaining this incredible rate was no longer possible, and today the technology is moving at a more sustainable pace of about 30 to 40% per year.



CGR : compound growth rate
MR : magnetoresistive
GMR : giant MR
AFC : anti-ferromagnetically coupled
PMR : perpendicular magnetic recording

Fig. 3—Historical Areal Density Trends for HDD Products and Laboratory Demonstrations.
Historical areal density trends for HDD products and laboratory demonstrations. In the 1990's with the introduction of MR and GMR heads the areal density CGR increased from 25% annually to 60% and then 100%. In recent years growth has slowed to a more sustainable rate of 40% per year.

The most challenging technology component in an HDD is the recording head, the device that both writes (records) the data onto the disk and that reads (senses) the "magnetic bits." The heads in the early drives used the same inductive element for both writing and reading of the data. As areal density increases, the magnetic sensitivity of the reader must increase to be able to detect the decreasingly small magnetic fields coming from the disk. In 1991 a more sensitive sensor, the MR head developed in SJRC, was introduced. This head is based on a single ferromagnetic layer, which provides a change in resistance of about 2% (key figure of merit). By 1997, the GMR head, developed and first demonstrated at SJRC, replaced the MR head. When first introduced, GMR sensors had a resistance change of about 4%, although modern GMR sensors can achieve up to 15%. Extremely high-precision processing is necessary to manufacture these tiny magnetic structures (today less than 100 nm wide) and control the sub-nanometer-thick films required to reliably produce the quantum mechanical phenomena that provide their extreme sensitivity.

Another area of important technology advancement is in the recording medium, the thin film of magnetic

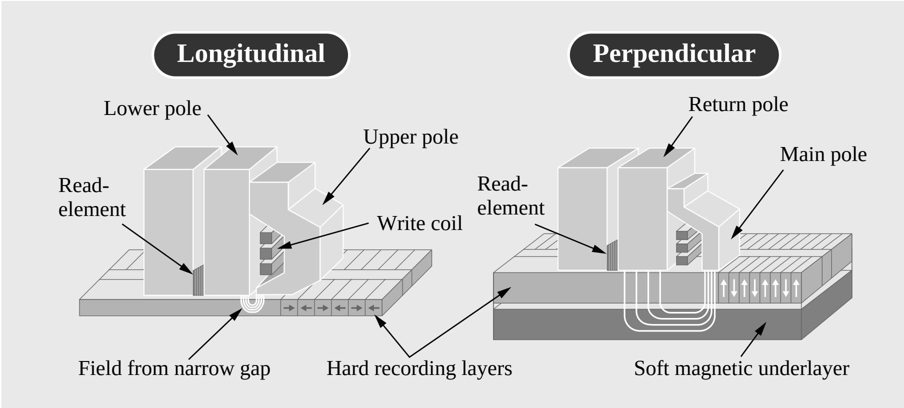


Fig. 4—Comparison of Longitudinal and Perpendicular Recordings.
Longitudinal recording aligns the data bits parallel to the surface of the disk. In contrast, perpendicular magnetic recording aligns the bits perpendicular to the disk, thus reducing the repelling forces between bits and allowing higher head fields, and enabling higher density.

material that coats the surface of the disk and stores the magnetic bits. The original disk-recording medium consisted of iron oxide particles dispersed in an organic binder that was spin-coated onto the disk. This technology was utilized well into the 1980s and then gave way to sputtered, thin-film, CoCr-alloy media. These polycrystalline films have evolved to the current longitudinal media, which use CoPtCrB-alloys with magnetic grain diameters below 10 nm. As the grain diameter of these thin films is scaled down to increase areal density, eventually their magnetic energy, which is proportional to their volume, becomes too small to withstand thermal fluctuations. At this point, the medium is no longer able to store data reliably. Considerable efforts to improve the media structures, for instance the use of layered heterostructures (e.g. AFC media invented at SJRC), have held off the onset of this thermal effect and allowed areal density to increase to levels higher than originally predicted.

As the limit of areal density achievable with LMR (longitudinal magnetic recording) is approaching, a new technology called PMR (perpendicular magnetic recording) (see Fig. 4) is being prepared to displace it. In March 2005, Hitachi GST demonstrated in a laboratory experiment a world-record areal density of 230 Gbit/in^2 using PMR technology, doubling the highest data densities achieved with LMR technology. In May 2006, after years of development in research and extensive global collaboration among research and development teams, the first Hitachi product using PMR technology, the Travelstar 5K160 with an areal density of 131 Gbit/in^2 , was launched into volume production.

FUTURE DIRECTIONS

Experts estimate that PMR technology will scale by utilizing incremental improvements and continued optimization to recording densities of 500 Gbits/in^2 or slightly beyond before reaching thermal stability limitations. In order, though, to meet the growing consumer demands and continue the annual areal density growth of 30 to 40%, new technologies to extend magnetic recording into the Tbit/in^2 regime will have to be developed in the next few years. One of the leading contenders in this quest is a technology called patterned media (see Fig. 5).

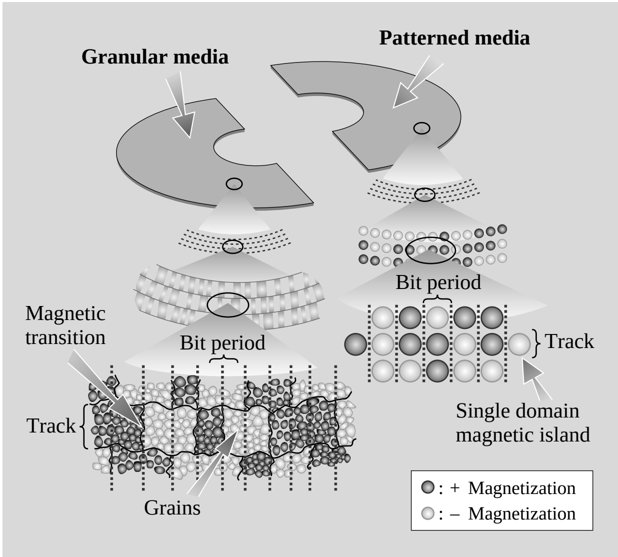


Fig. 5—Outline of Patterned Media Technology.
Patterned media replaces the many random, small grains of continuous film, granular media with one larger magnetic island that acts to store a single bit. By making the islands larger than the individual grains, the magnetic bits can be scaled to smaller size (i.e. higher density) and remain thermally stable.

Some of the key challenges for patterned media include developing an inexpensive, reliable, high-volume process to manufacture the disk, solving signal processing problems in how to address the bits, materials work to achieve the appropriate magnetic properties, and tribological solutions to allow the recording head to fly over the media surface at a spacing of less than 5 nm.

For recording densities above 500 Gbit/in^2 , new, more sensitive sensor technologies are required for the read head. A number of approaches are being explored, such as current-perpendicular-to-the-plane GMR devices and semiconductor-based spintronics sensors.

As the usage of HDDs in novel applications expands, so do the requirements on the HDD. To meet these requirements, the HDD will need to incorporate new features, such as flash memory for non-volatile cache, enable digital rights management compatibility, and provide encryption and security hardware and firmware capabilities. In addition, enhancing the HDD performance in multi-stream audio-visual applications may require more than just HDD functionality. For instance, it may require embedded file systems optimized for streaming data. These latter projects on system-level integration are the topics of research of a recently established and rapidly growing group of scientists at SJRC and the other research sites.

CONCLUSIONS

To continue the progress and evolution of the HDD over the next 5 to 10 years will require substantial investments in research and development to generate the understanding and knowledge of how to extend the existing technologies and how to create the necessary, new technologies. Based on the talent and global diversity of its HDD research efforts, Hitachi is well positioned to continue to be a technology leader in the future.

ABOUT THE AUTHORS

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