Information Storage Industry Consortium (INSIC)
[formerly National Storage Industry Consortium (NSIC)]

Cooperative Effort Leads to Magnetic Recording Innovation

One key technology driving the explosive growth of the computer industry in the late 1980s was magnetic storage technology that recorded data as a pattern of magnetic domains on a disk. As of early 1991, the best commercial disk drives could store less than 100 million bits of information per square inch. Memory-hungry applications, such as graphics, video images, and visually oriented user interfaces, demanded that increasingly more data be packed even more densely onto disks. The problem was that traditional inductive recording heads were rapidly approaching their technological limitations and could not expand enough to handle the new applications. In 1991, IBM introduced disk-drive products containing magnetoresistive (MR) recording heads, which enabled greater recording densities than the industry-standard thin-film inductive head.

The National Storage Industry Consortium (NSIC) proposed to vastly improve the potential for MR head technology through an award from the Advanced Technology Program (ATP). NSIC's goal was for industry members to work together on head technologies and, within five years, to demonstrate in the laboratory magnetic recording at 10 gigabits per square inch. NSIC aimed to accomplish its dramatic goal by providing a forum for industry competitors to work together, using ATP funds on early-stage research and then to take the research back to their labs for separate product development efforts. When the ATP project ended in 1997, the U.S.-based magnetic recording industry had removed the major technical barriers to achieving recording densities of 10 gigabits per square inch. The resulting giant magnetoresistive (GMR) heads were quickly adopted by the magnetic recording industry. By early 2000, 100 percent of new personal computers used GMR head technology.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 91-01-0016 were collected during October - December 2001.

Inductive Head Magnetic Recording Improves Slowly

By 1991, the rate of improvement in magnetic recording, typically occurring at less than 30 percent per year (or by a factor of 10 in 10 years), was not keeping up with advances in computer software capabilities. The read-write head technology that sustained the hard-disk-drive industry was based on inductive voltage produced when a permanent magnet (the disk) moves past a wire-wrapped magnetic core (the head). Early recording heads were fabricated by wrapping wire around a laminated iron core, analogous to the horseshoe-shaped electromagnets found in elementary school science classes. Market acceptance of hard drives, coupled with increasing memory-density requirements, fueled steady advances in inductive recording heads. This progression culminated in advanced thin-film, inductive read-write heads that were fabricated using semiconductor-style processes in volumes large enough (greater than 500 million heads per year) to meet the data storage demands of the computer industry. Even though advances in inductive read-write head technology were able to keep pace with increasing data storage density requirements, the cost-effective manufacture of these heads was projected to approach its natural limit by 1995. The biggest problem limiting further advances in inductive head technology

was the structure of the recording head itself. The structure required the head to alternate between writing data on the disk and retrieving previously written data, which required compromises in head design to serve both functions. Industry recognized that a new recording head technology would be needed to fuel continued growth in capacity and performance.

Magnetoresistive Heads Promise Continued Recording Improvements

In 1991, IBM introduced the industry's first disk-drive product to use a magnetoresistive (MR) head, which separated the write and read functions into two physically distinct portions of a combined head. An inductive head, optimized for writing information, was integrated with an MR head, which was optimized for reading. This technology represented a breakthrough for the magnetic recording industry and was quickly incorporated into products.

Industry-Wide Effort Required to Resolve Remaining Risks

The National Storage Industry Consortium (NSIC) proposed to vastly improve the potential for MR head technology with the help of an ATP award. NSIC's goal was for industry members to work together on head technologies and, within five years, to demonstrate in the laboratory magnetic recording at 10 gigabits per square inch.

Achieving this desired performance required a revolutionary approach to the design and fabrication of magnetic heads that no one company could afford to explore alone.

Achieving NSIC's goals for such increases in storage density so quickly was no small task. Ten gigabits per square inch of data storage required each recorded bit to occupy an unusually small area on the recording medium.

The energy in the magnetization of that small area on the disk would have to be of similar scale. The need, therefore, was to develop heads that could accurately detect these tiny magnetizations. The heads would need to provide sufficient signal-to-noise detection capabilities so that data could be recorded and read with error rates low enough to enable system performance of not more than one error in 10^{14} bits. Achieving this desired performance required a revolutionary approach to the design and fabrication of magnetic heads that no one company could afford to explore alone. Paradigm shifts in design, materials, and fabrication technologies were required. NSIC's ATP project was predicated on creating and optimizing these shifts, then allowing the recording industry to use the resulting series of innovations in product development.

Much of the U.S.-based magnetic recording industry and many universities joined NSIC to work on this project. Eight companies joined the project at the start (Applied Magnetics, Digital Equipment, Eastman Kodak, Hewlett-Packard, IBM, Maxtor, Quantum, and Read-Rite), along with seven university centers (Data Storage Systems Center at Carnegie Mellon University, the Center for Magnetic Recording Research at University of California-San Diego, the Center for Materials for Information Technology at the University of Alabama, the Center for Micromagnetics for Information Technology at the University of Minnesota, the Center for Information Storage Materials at Stanford University, the Institute for Magnetics Research at George Washington University, and the Magnetic Information Storage Center at Washington University in St. Louis). Seagate and Censtor joined the project after it started, and Maxtor left the project when it temporarily became foreign owned. Digital Equipment sold its data storage business to Quantum. Several national laboratories also participated in the collaborative effort.

NSIC Foresees Sizeable Benefits to U.S. Economy

If NSIC succeeded in significantly accelerating magnetic recording density progress, the results for the industry, for computing applications, and for the U.S. economy would be staggering. Given the projected 14-percent annual growth rate in the disk storage market from 1997 to 2001, one additional percentage point in market share could have a billion-dollar impact. Moreover, a substantial improvement could enable entirely new computing applications, with spillovers across the computer industry and every industry that uses magnetic recording to store data. Finally, even if the project failed, NSIC's efforts could significantly reduce duplicative research across the industry.

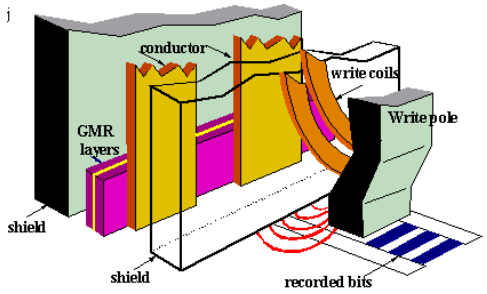
The capital and personnel demands for NSIC's project were too daunting for any single, private firm to meet. In the words of Jim Brug, a researcher at Hewlett-Packard Laboratories who served as project leader for NSIC, "…[giant MR] recording heads take hundreds of people to make."[1] There are so many materials to test, methods to explore, and processes to improve that it would take years and millions of dollars for individual companies to explore them all separately. In the magnetic recording business, that kind of time and money is prohibitive for individual companies. It took NSIC's ATP award to galvanize the industry to work toward a common goal even though the individual firms (much less the entire industry) would not capture all of the economic benefits of the project.

Paraphrasing the words of Dr. Brug, the ATP project gave participants the knowledge to be able to improve the heads well beyond what was imaginable in 1991.[2]

NSIC Solves Technical Issues Relating to GMR Heads

The consortium started from scratch with recently introduced MR heads, working with completely new design concepts. The consortium members faced issues that fell into technical and organizational/logistical categories.

The technical issues were remarkably daunting. Projecting out two years from project start, MR technology would require material layers of a thinness unheard of in the magnetic recording industry. The industry would need to make 800 million heads with MR read heads made up of layers of materials, some of which were only a few atoms thick. Finding materials that kept their useful properties when cut into several atoms' width was difficult enough. Creating processes for mass-producing such materials was considered nearly impossible. Through the project's first three years, NSIC members modeled and tested a variety of different types of MR heads that could be used to read and write information at high densities, providing the requisite research to develop GMR read-head technology. Similarly, NSIC researchers accomplished pioneering work in write-head materials and fabrication processes that also demonstrated the capability to write



A cutaway schematic of a GMR Head device developed during the ATP project.

data at 10 gigabits per square inch onto the magnetic disk-a necessary complement to the GMR read-head research.

Because of the variety of interacting magnetic layers in the head structures, the design of the heads was critical given the extremely small dimensions required for this project. One misstep could throw off the magnetization or could cause the read head to fail to read information properly. To ensure the tightest tolerances, NSIC members developed and used advanced micromagnetic models to study whether conventional longitudinal recording (magnetization in the plane of the media) was capable of achieving the desired recording density of 10 gigabits per square inch. This was a significant question in the industry because Japanese companies had long advocated perpendicular recording (magnetization perpendicular to the media) as capable of achieving higher data densities. After extensive modeling, NSIC's project showed that longitudinal recording would produce the desired effect with the fewest technical issues.

In terms of organizational/logistics, representatives from all the companies and universities had too many different ideas on head design, materials choice, and fabrication techniques for any one company to make these decisions. NSIC's project participants therefore took it upon themselves as a group to determine which materials worked best. This task required thousands of research hours, conducted in parallel, at each of the participating institutions and hundreds more hours compiling the data and discussing which method worked best. This cooperation was a remarkable aspect of the ATP project; companies that were trying to drive each other out of business in the marketplace were actually cooperating with one another on precompetitive

1. *Email conversation with Jim Brug, August 10, 2001.*
2. *Ibid.*

competitive research to come up with the best possible materials and methodologies for GMR heads.

Using GMR Head Technology Leads to Product Introductions

After the initial research, multiple companies integrated GMR head technology into a variety of products that resulted in truly remarkable capabilities. The first product to hit the market using GMR technology was IBM's Deskstar 16GP™.

The product was announced in the last quarter of 1997 (less than six months after the end of the NSIC ATP project) and shipped in volume starting in the first quarter of 1998. GMR technology also enabled a 73-gigabyte hard drive, IBM's Ultrastar 72ZX™, which at the time was the largest hard drive ever made. The hard drive, used for transaction processing and digital documentation, could store seven billion data bits per square inch. Roughly the size of a paperback novel, it could hold as much information as a floor of books at the New York Public Library (with room to spare).

In the highly competitive magnetic recording industry, companies are known to rapidly outpace one another. For example, less than six months after IBM introduced the Ultrastar model, Seagate announced the demonstration of technology that could store 20.8 billion bits (gigabits) per square inch. IBM followed by announcing a 20.3-gigabit laboratory demonstration in May 1999 and another 35.3-gigabit demonstration in October 1999, nearly doubling demonstrated density within six months! By mid-2002, laboratory demonstrations using GMR heads had achieved the astounding level of 103 gigabits per square inch.

These developments in GMR head technology have enabled the U.S. industry to deliver hard-drive products that serve a multitude of application environments. Examples include:

- Drives with extremely high capacity, such as the Barracuda 180 drive from Seagate (with a total capacity of 181.6 gigabytes) and Western Digital's 200-gigabyte Caviar® "Drivezilla" drive
- Drives with rotational speeds as great as 15,000 revolutions per minute to provide very-high-speed access and transfer of data (such as the high-performance models of IBM's Ultrastar and Seagate's Cheetah drive families)
- Drives designed with a single disk platter to permit low product cost while providing astonishing capacities of 60 to 80 gigabytes from Maxtor, Seagate, Western Digital, and others
- Small, form-factor, mechanically robust drives with capacities as great as 60 gigabytes (IBM's Travelstar 60GH product) to serve the mobile computer market
- The miniaturized IBM Microdrive that provides one gigabyte of storage in a package weighing less than 16 grams for use in digital cameras and other handheld consumer electronics

NSIC Changes Magnetic Recording in Record Time

The GMR head technology that resulted from the ATP project changed the magnetic recording industry. Once it was apparent that GMR heads improved data storage density nearly hundredfold, industry moved quickly to adopt the technology. By the last quarter of 2000, the new technology had been fully adopted by the U.S. industry: all hard drives manufactured by U.S.-based companies used GMR heads. In other words, GMR heads achieved a 100-percent market penetration in three years. In comparison, thin-film inductive heads took 15 years to be adopted as the industry standard, and conventional MR heads took 5 years.

GMR head technology also has the potential to further change the magnetic tape recording industry via two distinct scenarios. First, as future generations of tape recording technology evolve toward much higher track densities and thinner magnetic media, GMR heads, because of their ability to provide the required additional signal-detection sensitivity, will probably replace conventional MR heads.

At the same time, continuing improvements in hard-disk technology afforded by the use of GMR heads are providing disk storage arrays with newly emerging opportunities in applications that have traditionally been served by tape. These include backup and restore functions in computer environments ranging from large enterprises to small businesses.

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This wave of new products contributed to an increase of eight percent in the U.S. market share of global magnetic recording devices. At the start of the ATP project, U.S.-based companies held a 62-percent global market share. As of the last quarter of 2000, when GMR heads completely penetrated the industry, U.S.-based companies held 70 percent of the global market share, with Japanese companies holding the next largest portion. Japanese firms have recently formed their own NSIC-like consortium to try to compete with U.S.-based firms. NSIC was later renamed the Information Storage Industry Consortium, or (INSIC).

Conclusion

ATP funded the efforts of NSIC to coordinate an extensive research and development process designed to significantly advance MR head technology. As a result of comprehensive materials testing and modeling, GMR head technologies enabled an extensive set of new data storage products. Although a completely integrated magnetic recording demonstration at a density of 10 billion bits per square inch was not carried out within the timeframe of the ATP project, the resulting technology represented such a significant advancement over earlier technology that, within three years after the ATP project ended, 100 percent of all hard drives produced used GMR technology.

PROJECT HIGHLIGHTS
Information Storage Industry Consortium (INSIC)
[formerly National Storage Industry Consortium]

Project Title: Cooperative Effort Leads to Magnetic Recording Innovation (Ultra-High-Density Magnetic Recording Heads)

Project: To develop technology for new data recording heads capable of writing and reading 10 gigabits per square inch; a hundredfold improvement over the best commercial devices available when the project began.

Duration: 8/1/1992-7/31/1997
ATP Number: 91-01-0016

Funding (in thousands):

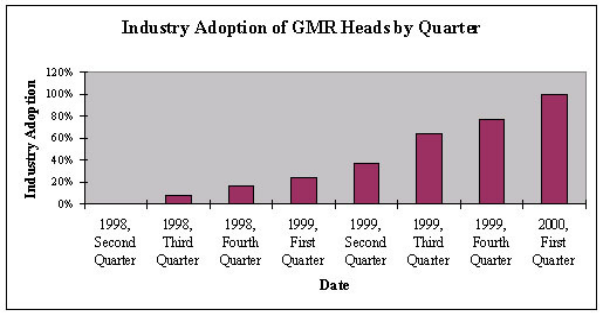
ATP Final Cost	$ 5,457	48%
Participant Final Cost	5,984	52%
Total	$11,441	

Accomplishments: This ATP-funded project was remarkably successful. The research and development process helped to create giant magnetoresistive (GMR) heads that could record nearly 100 times more information per square inch of recording medium than the heads that were commercially available at the time. The successes of the ATP project included:

- Coordinating hundreds of researchers across the country on a single project
- Achieving a technological breakthrough that industry experts initially believed was impossible
- Combining films of existing materials to create new devices that, at just a few atoms' thickness, exhibited the required magnetic properties
- Creating read and write heads so exact that errors occurred no more than once in every 10^{14} bits
- Developing a technology that 100 percent of the industry adopted within three years
- Enabling an additional eight-percent global market share for U.S.-based companies

NSIC coordinated efforts among hundreds of researchers to set an industry standard for the very best magnetic recording heads possible. Subsequent related products pushed the envelope of magnetic recording farther and faster than ever.

Commercialization Status: Before the ATP project, GMR head technology did not exist, and magnetic inductive head technology was rapidly reaching its technological zenith. During the ATP project, researchers settled on the GMR head design and on specific materials to use in its fabrication. After the ATP project ended, GMR head technology received such broad and fast industry adoption that it became the industry standard in record time, as shown in the chart (source: Morgan Stanley Dean Witter Disk Drive Industry Update, June 15, 2001).



The previous two generations of magnetic recording head technology took 15 and 5 years, respectively, to become the standards. GMR heads took less than three years to achieve total market domination. Until the next generation of technology replaces GMR heads, companies will continue to use the technology in every hard drive they produce.

Outlook: The GMR head technology that benefited from the ATP project changed the face of magnetic recording. When GMR heads enabled a nearly hundredfold improvement, the industry moved as fast as it could to adopt the technology. GMR technology currently dominates the marketplace. Industry competitors are still rushing to improve the technology as quickly as possible to surpass their competitors. This dynamic should continue for the foreseeable future; the outlook for GMR head technology is outstanding within the magnetic recording industry.

Composite Performance Score: * * *

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Research and data for Status Report 91-01-0016 were collected during October - December 2001.