NONVOLATILE ELECTRONICS, INC. (NVE)

Computer RAM Chips That Hold Memory When Power Is Off

Conventional random access memory (RAM) computer chips record information written or copied into them by a computer, and they hold that data as long as electricity flows through the chips. Once the power is turned off, the information is lost unless it has been saved to a floppy disk or to the computer's hard disk, which hold data even when the power is off. Many computer users have learned this fact only after a power outage or other mishap suddenly erases the data they were working on. Program manuals and technical support staff repeatedly advise computer users to save often.

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

RAM That Remembers Without Power

If a memory chip could store data permanently, it would prevent these accidental loses of information. And if it could be produced in small sizes at competitive costs, the new chip would greatly affect how computers are configured and used. For example, an insertable card containing memory chips (which have no moving parts) could be substituted for a hard disk drive.

Civilian Use of MRAM Technology

This ATP project with Nonvolatile Electronics (NVE), founded in 1989 (and operated from the founder's house until the ATP award), aimed to develop such a memory chip. The founder co-invented "magnetoresistive" RAM (MRAM) technology for defense applications while at Honeywell, which subsequently licensed the technology to NVE for civilian uses. For these applications, the technology had to achieve greater density, signal strength, and production yield to meet cost considerations, which are more important in consumer markets than in the military market.

GMR sensors have many applications . . .

A metal is magnetoresistive if it shows a slight change in electrical resistance when placed in a magnetic field.

The clean room at Nonvolatile Electronics in which GMR sensors and other devices are fabricated.

In 1988, scientists discovered that a sandwich of metals shows a much larger change in resistance than a single metal of the same size. This effect was named "giant magnetoresistance," or GMR.

Researchers at NVE saw the use of GMR materials as a way to achieve advances in signal strength, and they made important advances in the producibility of GMR materials. They also achieved the project's circuit density goals and made substantial improvements to production throughput, or yield. These developments are all important for lowering barriers to commercializing the technology for civilian applications. The researchers made prototype high-quality MRAM cells that were successfully demonstrated at Honeywell.

PROJECT HIGHLIGHTS

Project:
To develop magnetoresistance technology for use in making computer random access memory (RAM) "nonvolatile" — data will not be lost when power is turned off.

Duration: 4/1/1991 — 3/31/1994
ATP Number: 90-01-0166
Funding (in thousands):

ATP	$1,785	67%
Company	869	33%
Total	$2,654	

Accomplishments:
In its quest to develop magnetoresistive RAM (MRAM), NVE made significant advances in producibility, circuit density and signal strength by using giant magnetoresistance (GMR) materials. In the process, the company developed an important spinoff application of the technology in sensors. Indicative of progress, NVE:
- started producing an initial commercial product, a GMR magnetic bridge sensor, in 1994, selling about 50,000 by the end of 1997 to other companies for examination purposes and earning revenues of more than $150,000 that year alone;
- entered into an agreement with Motorola in 1995 to develop MRAMs (development is still under way, with sales possible in 1999);
- entered into an agreement with Microtrace in 1996 to use a GMR-based procedure to make counterfeiting of aircraft parts much easier to detect (development work is under way);
- licensed the ATP-funded technology to Honeywell (for use in military and avionics applications), which incorporated it into computer systems placed in government agencies; and
- transferred knowledge about GMR materials to members of an ATP joint venture working on technology for magnetic disk storage based on the GMR effect.

Commercialization Status:
NVE is successfully making and selling — with a recent growth rate of about 3,000 percent — GMR-based sensing products, a spin-off from its MRAM technology development project. It is also pursuing commercialization of MRAMs through an agreement with Motorola, an endeavor that could lead to a substantial share of a $45 billion/year market.

Outlook:
The outlook is excellent for expanded use of GMR sensors, which have many applications, including pace makers, engine control, shock absorbers, antilock brake systems, current monitoring, cylinder position sensing and automatic meter reading. The outlook for commercialization of the nonvolatile memory chips is potentially bright. But with several more years of development, the extent of use remains uncertain. Spillover benefits are potentially large.

Composite Performance Score: * * *

Number or employees: 10 at project start, 56 at the end of 1997

Company:
Nonvolatile Electronics, Inc. (NVE)
5805 Amy Drive
Edina, MN 55436

Contact: James M. Daughton
Phone: (612) - 996-1607

A Promising Spin-off Application

As NVE focused on GMR materials advances, it saw a potential spin-off application that received only marginal attention when the company started its ATP project: GMR sensors. A major application for sensors based on the new technology is possibly in antilock brake systems in automobiles and trucks. These systems use a clamp to grip the edge of a steel disk attached to the wheel. If the clamp grabs too tightly, the brake locks, the wheel stops rotating, and the tire slides on the road surface instead of gripping it. In an antilock brake system, a sensor detects the rotation of the disk and feeds hat information into a computer. If the computer detects overly rapid deceleration — indicating the brake is about to lock — it directs the braking mechanism to reduce clamp pressure to keep that from happening.

The new NVE sensors are substantially more sensitive than conventional sensors. They can be farther from the monitored object while performing equally well. Their magnets can be smaller, so the cost is less. And the NVE sensors can detect rotational speeds closer to zero, which means the computer receives more accurate data to use in controlling the brake mechanism. In a vehicle equipped with an antilock brake system incorporating NVE sensors, the driver will have better skid and stopping control.

Product Sales and Commercialization Agreements

NVE expects to apply its sensor technology in several

In a vehicle equipped with an antilock brake system incorporating NVE sensors, the driver will have better skid and stopping control.

other industries, too, including medical devices, consumer products, and machine tool manufacturing.

Production for these markets is planned for the near future. According to NVE, it is the first to make and sell GMR-based sensing products for the general market, and it has established a new company division for this purpose. Its sales of GMR-based sensors have grown by about 3,000 percent recently, from around $5,000 in 1994 to more than $150,000 in 1997. The company has also generated revenues from engineering contracts, as well as royalties from companies that license its technology.

Photomicrograph of a GMR magnetic field sensor, with actual dimensions of 436 X 3370 microns.

NVE entered into an agreement with Motorola in 1995 to develop MRAMs, and the development work is under way. Production could begin in 1999. If this effort succeeds, NVE expects to capture a sizable share of the $45 billion annual market for memory and hard-disk drive products. The company also signed an agreement with

NVE entered into an agreement with Motorola in 1995 to develop MRAMs . . .

Microtrace in 1996 to use a procedure based on GMR techniques to make counterfeiting of aircraft parts much easier to detect. The development work is under way, and products for this application are also expected in 1999.

For GMR applications beyond its own pursuits, NVE has offered its knowledge to other companies, universities, and national laboratories. This was done through another

NVE has offered its knowledge to other companies, universities and national laboratories.

ATP project (#91-01-0016: “Ultrahigh-Density Magnetic Recording Heads”) conducted by a large joint venture led by the National Storage Industry Consortium. NVE officials consulted on fabrication methods for making GMR films and supplied samples of the films made by NVE.

Benefits From the Technology

Because NVE is selling only sensors, all benefits will initially come from that product. When the sensors actually begin appearing in commercial products — some time after 2000 — end users will have access to competitively priced devices that operate at much greater temperature extremes than do conventional sensors. Additional benefits will accrue from GMR sensors as more are used in a variety of applications.

GMR sensors will likely generate substantial economic benefits beyond those realized by NVE. A sensor is a small part of an antilock brake system, which is a small part of a much larger device — an automobile. Several manufacturing and subassembly stages lie between the development of the sensor and the final product, and the sensors add value to the product at each stage. According to NVE, the total of this spillover benefit will likely be more than 10 times greater than what the company earns for the use of its new technology. And the aggregate benefit will increase as more cars are equipped with antilock brake systems incorporating NVE sensors. Spillover benefits promise to be even larger when the sensors are used in other applications.

In addition to these applications, the company’s GMR sensors are being used for portable traffic monitoring instruments, and they may be very useful for instruments used to detect land mines. Geometrics, Inc., in Denver, Colorado, has contracts to design and test devices to detect antipersonnel mines for the U. S. military, and it has subcontracted with NVE to supply GMR sensors for the detectors. If the design and testing lead to workable detection instruments, a much better job of finding and removing unwanted land mines will be the result. There are 100-200 million such land mines throughout the world in areas that were formerly areas of warfare, and they kill and maim tens of thousands of innocent people each year.

The market for MRAMs — the application initially targeted by NVE — may eventually be important, but it is still in the future. If MRAMs ultimately reduce accidental loss of information to computer users, benefits will be large.

ATP Project Saves Company

Before the ATP project, NVE was a tiny, undercapitalized company facing significant

technological risks in developing the technology for commercial uses. Funding from the ATP, however, enabled the project to be done and prevented the company from failing, NVE officials say. In addition, the ATP award improved the company's ability to attract capital from other sources.

Funding from the ATP enabled the project to be done and prevented the company from failing . . . and improved the company's ability to attract capital from other sources.

This status report was written during 1997-98 and published in March 1999.