IBM is proposing a novel idea for storing data: a thousand cantilever legs crawling across the surface of a futuristic hard drive

Millipede: Probing the Future

Paul Vettiger, Switzerland

Today's data storage is dominated by the use of magnetic disks. Two-hundred million of them are installed each year as hard disk drives in PCs, laptops, servers and mainframes. The data storage density in these disks has been increasing by 60% annually over the past 10 years—more recent improvements are giving 100% growth a year. A hard disk drive (HDD) sold at the start of this millennium manages nearly 1.5 Gb/cm^2. But the world record for density in a research laboratory is currently 5.4 Gb/cm^2, and this is being pushed to higher values. However, there may be a physical limit. It has been predicted that superparamagnetic effects—the bit size at which stored information becomes volatile as a function of temperature and time—will limit the densities of current longitudinal recording media to about 15.5 Gb/cm^2. *Figure* 1 shows the density evolution in HDD products and research demonstrations. The limit, and the fast-growing density, makes it clear alternative approaches to the current longitudinal recording scheme need to be explored. Perpendicular and patterned magnetic media are currently being investigated by many research teams around the world.

For the past four years, the micro and nanomechanics group at the IBM Zurich Research Laboratory in Switzerland has been exploring an alternative storage approach based on scanning probe techniques. Mechanical scanning probe techniques, specifically scanning tunnelling (STM) and atomic force microscopies (AFM), have demonstrated the potential of mechanics at the micro/nanometer scale not only for imaging, but also for modifications and even for the precise positioning of individual atoms and molecules.

The movements of tiny mechanical components consume very little energy and can be quite fast. Micro and nanomechanical devices have become very attractive owing to the development of new micromachining techniques that allow industrial "batch" fabrication similar to silicon chip manufacturing. This has opened up the VLSI (very large-scale integration) age of micro and nanomechanics, which promises the integration of mechanics and electronics on a single chip.

Scanning probe techniques such as STM and AFM have great potential for very high storage density. Several years ago a group at IBM's Almaden Research Center in San Jose, California, pioneered micromechanical data storage based on AFM technology by using a tip integrated on a silicon cantilever and operating it over a spinning disk, similar to the setup of a magnetic storage disk drive. A read-only scheme used disks replicated from a master, and sensed 100-nm-sized features by means of an AFM cantilever as "0" and "1" at densities of up to 10 Gb/cm^2 (100 times more than that of a CD Rom). In an experimental write-once/read-only scheme, an AFM tip heated by electrical pulses generated indentations in the polycarbonate disk. These indentations represented the data bits at densities greater than 4.5 Gb/cm^2. Mechanical response times allowed read data rates of up to a few megabits per second (Mb/s).

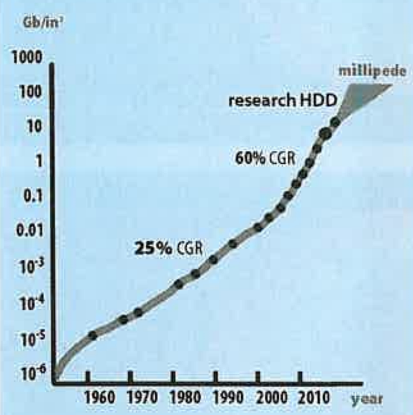

Fig 1 Over the past 50 years the density for storage on hard disk drives has increased by almost seven orders of magnitude. Disk density here is shown in the industry standard Gigabits per square inch. The conventional magnetic head decreased in size until the early nineties, when it was replaced by a magnetoresistive head. This change boosted the compound growth rate (CGR) from 25 to 60%. The millipede concept constitutes a new concept for achieving high storage densities beyond current physical limits

The low write/read data rate, which was a major drawback of this approach, has since been addressed by researchers at the IBM Zurich Research Laboratory. The 200 to 300 Mb/s data rate of today's HDD products can only be achieved or improved by the highly parallel operation of a large number of scanning probes. In other words, thousands of tips/cantilevers had to be integrated densely on a small silicon chip to serve as a write/read head.

This new concept, called the millipede, is not a modification of an existing storage technology, although the use of magnetic materials as storage media is not ruled out. The ultimate storage density is given by the tip, whereas the high data rates are a result of the massive parallel operation of such tips. The basic millipede concept is illustrated in *figure* 2. The two-dimensional cantilever array chip acts as the parallel write/read head, the storage medium being mounted on a magnetically driven scanner. In operation, the medium first approaches the array chip by means of three actuators until three sensors on the array chip detect contact between the chip and the medium. This contact is maintained during operation by three external feedback loops. Write/read operation is performed while the medium is scanned in x and y directions in a raster scan mode. The x and y scanning distances correspond to the pitch between two tips. Electronics controls the quasi-parallel operation of the array; one line is operated in parallel while the others are addressed in a time-multiplexed sequence. The photographs and scanning electron micrographs on the right of the page show the fabricated array chip with 32 by 32 (1024) integrated AFMs. The entire cantilever array is only 3 by 3 mm^2 and is electrically interfaced to the array electronics via the peripheral bonding pads.

The current approach uses the following as the storage medium: a 50-nm-thick polymer film of PMMA (polymethylmethacrylate) spin-coated on a silicon substrate. A thermomechanical process is used for both writing and reading. During writing, the heater platform at the end of the cantilever with the tip on top is heated, which locally softens the polymer. In conjunction with the small force on the cantilever, the sharp tip forms a nanometer-sized indentation into the polymer film. For reading, a similar thermomechanical process is used. While the tip scans over an indentation, the heater platform is cooled by the smaller airgap generating a resistance change, which is detected as read-back signal. Using single cantilevers, the IBM Zurich team has demonstrated an areal storage density of

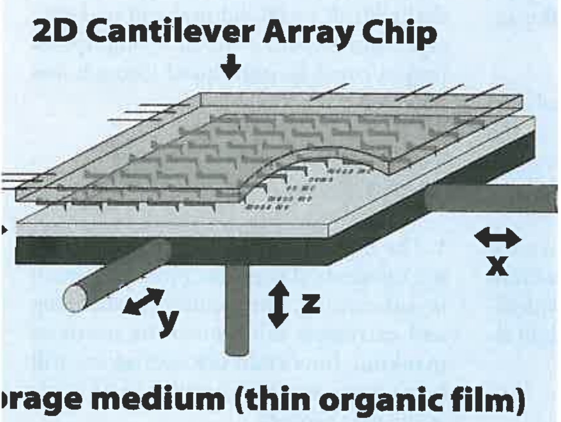

Fig 2 Schematics of the millipede storage concept

Right images of the array chip and cantilever

60 to 80 Gb/cm^2 by means of this thermomechanical write/read process. An array of 40-nm-sized indentations is also shown in *figure* 2.

In addition, erasing and rewriting capabilities of polymer storage media have been demonstrated for the first time. Erasing is achieved by thermal reflow of storage fields as the medium is heated to about 150°C for a few seconds. The smoothness of the reflowed medium allows a storage field to be rewritten repeatedly. Although this erasing process does not allow single-bit erasing, it can erase larger storage areas.

Whereas densities of 60 to 80 Gb/cm^2 have been achieved with single cantilevers, the IBM Zurich team has recently demonstrated the first parallel write/read operation of a 32 by 32 array chip. Densities of up to 30 Gb/cm^2 have been reached, and the potential to match or exceed those of single cantilevers has been found.

This opens up interesting prospects for storage systems. Assuming a storage density of 80 Gb/cm^2, such a system could store 10 Gigabits of data in an area of about 3 by 3 mm^2. This demonstrates the potential for a very small-form-factor storage device because the scanner is also fabricated and integrated in silicon. In addition, the process technology developed for the array chip will even allow the fabrication of considerably larger and more densely integrated AFM arrays. The actual multiplexing electronics is based on available vendor components, but the next generation will be integrated on the array chip.

A tiny form factor, large storage density, high data rates, and low power consumption are features that make this concept very interesting for future mobile computing applications in laptops, cellular phones and watches. It is important to note that the millipede concept is not limited to polymer storage media. Provided that the write/read functionality for a given medium can be integrated on the cantilever/tip, the concept can be adapted to any medium.

The project is still in an exploratory stage with many open questions and issues to be addressed prior to possible commercialization. However the millipede concept will find applications not only for data storage, but also for metrology, defect and quality control, imaging, nanolithography, and in other fields where nanometer-scale resolution and high throughput are essential.

The original vision of this project was inspired by nature's millipede, whose one thousand legs operate in parallel. Hence it became the namesake of our project. □

The author is manager of the micro and nanomechanics group at IBM's Zurich Research Laboratory in Switzerland. His co-authors are: Michel Despont, Ute Drechsler, Urs Dürig, Walter Häberle, Mark I. Lutwyche, Hugo Rothuizen, Richard Stutz, Roland Widmer, Gerd Binnig

Further reading

Ultrahigh-Density Atomic Force Microscopy Data Storage with Erase Capability by G. Binnig *et al Appl. Phys. Lett.* **74** 9 1329-1331 (1999) • Ultrahigh Density, High-Data-Rate NEMS-Based AFM Data Storage System by P. Vettiger *et al J. Microelec. Eng.* **46** 1-4 11-17 (1999) • The Millipede: More than one Thousand Tips for Future AFM Data Storage by P. Vettiger *et al IBM J. Res. Develop.* (1999) in press