Excerpt

TRN's
Making the Future Report

The State of an Emerging Technology and a Look at What Lies Ahead

Report Number 2

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Data Storage: Pushing the Physical Limits

Executive Summary

The gap between data storage research and the market has never been smaller.

In the next five years, data storage technology is likely to advance along the familiar course of electronic memory chips, magnetic disk drives and CD-like removable media. Meanwhile, research in materials science and nanotechnology is paving the way for future storage media with huge capacities.

Patterned media, which should be ready for applications in five years, is likely to bridge the gap between today's magnetic disks and future technologies.

There are several new media that could be ready for practical application in five to ten years:

- Arrays of nanowires
- Patterns of electric charges or magnetic particles stamped into thin films of plastic
- Holograms
- Single or small groups of molecules, including carbon nanotubes

Superfast microelectromechanical systems (MEMS) storage devices that use thousands of read/write heads, each positioned over a small area of recording media, could also be ready within the five to ten year time frame.

The future storage media with the potential to store the most data per square inch is the atom. A prototype from the University of Wisconsin records bits as the presence or absence of individual atoms, and has a capacity of 250 terabits per square inch, enough to store 10 DVDs worth of data on a pinhead. Practical applications however, are one to two decades away.

What to Look For

Disk drives:

Patterned media
Terabit-per-square-inch patterned media

... and 11 more developments to look for.

Who to Watch

Media and Materials:

Orlando Auciello, Argonne National Laboratory
Argonne, Illinois
www.msd.anl.gov/groups/im/people/auciello.html

Bruce Terris, IBM Research
San Jose, California
www.almaden.ibm.com/st/projects/patternedmedia/

... and 18 more researchers to watch.

Smaller bits

Nobel laureate Gerd Binnig is making a data storage device out of a thousand microscopes. The chip-size system will be able to hold many gigabytes of data, enough to let a credit-card-size digital camera store thousands of pictures.

Hans Coufal is working out the kinks in a system for storing massive amounts of data in small pieces of glass or plastic. The method stores pages of data as holograms that can be retrieved all at once, making it much faster than today's disk drive technology.

These are among dozens of data storage projects being pursued by just one organization — IBM Research.

In today's technological society data storage is ubiquitous, and the weight of the installed manufacturing base is pushing much of the research toward improving existing technologies. There is also tremendous incentive for coming up with radically better alternatives.

The stakes are high. The business community is accustomed to bit densities doubling every 12 to 18 months, and, according to IBM Research, the gap between research and the market has never been smaller.
(www.almaden.ibm.com/st/disciplines/storage/)

The bottom line in data storage research is making bits smaller so storage devices can hold more data. There are three approaches:

- Pushing the limits of today's technologies to make smaller bits
- Using new technologies to produce smaller bits for today's devices
- Making entirely new devices

Basic and applied research, particularly in materials science and nanotechnology, is paving the way for storage media with huge capacities. Some researchers have made great progress toward new types of devices, like microelectromechanical systems (MEMS). And the relentless drive for ever-smaller bits has pushed chemists and physicists rather than electrical engineers to the vanguard of data storage research.

This report assesses the state of data storage research and maps out the many roads ahead.

- The first section examines strategies for advancing today's magnetic storage technologies, focusing on efforts to make small magnetic domains stable.

- The second section covers emerging storage media made possible by nanotechnology.

- The third section looks at ways to locate, write data to and read data from incredibly shrinking bits, and details the devices being considered for these difficult jobs.

- The fourth section examines optical and holographic storage technologies and the hurdles researchers are struggling to overcome.

- The fifth section details initiatives aimed at storing bits in individual atoms and molecules, and looks at the ways the bottom-up approach to storage technology is being integrated with traditional, top-down manufacturing...

... the full version of TRN's Data Storage report also includes the following sections:

How It Works

Today's technology

The technology used to to read a bit stored on today's production magnetic disks is based on magnetoresistance, the change in the way a material conducts electricity in the presence of a magnetic field. The read head of a disk drive is a probe containing an electric circuit. The probe floats just above the surface of the disk, and when it encounters a tiny magnetic field produced by a bit recorded on a tiny portion of the disk, the resistance of the probe's circuit decreases. The type of bit — a 1 or a 0 — is determined by measuring the change in resistance.

In order to sense the smaller magnetic fields of smaller bits, read heads have to be more sensitive. Probes with greater magnetoresistance are able to sense weaker magnetic fields. Disk drives use giant magnetoresistance probes, which undergo a 100-percent decrease in resistance when they encounters a magnetic field.

Giant magnetoresistance occurs when two thin layers of magnetic material with opposite magnetizations are separated by a thin film of non-magnetic material. The giant magnetoresistance device changes resistance based on electrons' spins. Electrons spin in one of two directions, up or down, which correspond to the North and South poles of a magnetic field.

When a current of electrons attempts to pass through the layers, electrons spinning in one direction are blocked by one of the magnetic layers, and electrons spinning in the other direction are blocked by the other layer. In the presence of a magnetic field, the magnetization of the layer with the opposite orientation reverses. This brings the two layers into alignment, and the layers together block only electrons of one spin.

Very large, extraordinary, ballistic

There are several candidate technologies for more sensitive magnetoresistance: very large, extraordinary and ballistic magnetoresistance.

Very large magnetoresistance was discovered by researchers at Johns Hopkins University. The effect is produced in nanowires and single-crystal thin films of bismuth. Devices that use very large magnetoresistance undergo a 250-percent change in resistance at room temperature in the presence of a magnetic field, and so are more sensitive than those that use giant magnetoresistance.

Extraordinary magnetoresistance was found by NEC Laboratories America and is produced by sandwiching a thin layer of highly conducting metal like gold between layers of nonmagnetic semiconducting materials. Devices that use extra-ordinary magnetoresistance undergo as much as a 550 percent change in resistance when sensing magnetic fields similar to those of bits on disks.

Ballistic magnetoresistance, discovered by researchers at the Laboratory of Small Systems Physics and Nanotechnology in Spain and extended by researchers at the State University of New York at Buffalo, is produced at the junction of two nanowires. Because the junction is only a few hundred atoms wide, electrons flow straight through rather than bouncing from side to side the way electrons flow through larger wires. The change in resistance is greater than 3,000 percent, and the small size of the sensor makes it possible to read tiny, closely-packed bits.

MEMS

One technology that promises to store more information than disk drives is microelectromechanical systems. MEMS have electrostatic actuators — electrically-driven springs and levers — that can move components like storage media and read/write heads tiny, precise distances. The three principal MEMS storage projects — at IBM Research, Carnegie Mellon University and Hewlett-Packard Laboratories — use similar mechanics: arrays of thousands of microscopic tips positioned above rectangular sections of storage media that move short distances laterally and longitudinally relative to the tips. The three approaches record information differently.

The IBM device records bits by heating the tips to melt tiny pits in a plastic storage medium, similar to burning a CD. The presence of a pit represents a 1 and the absence a 0. The device reads bits by sensing changes in temperature. When a tip moves across the surface and falls into a pit, more of the tip is in contact with the surface, which causes it to dissipate heat more quickly.

The CMU device is comparable to a magnetic disk drive. Each tip is a miniature read/write head and the surface is magnetic. An actuator and sensor on each tip keeps the tip a precise distance above the surface to accommodate microscopic variations in surface height.

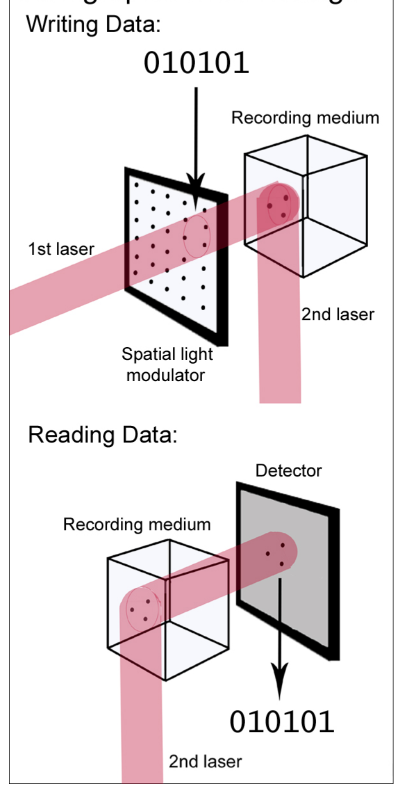
The HP device fires a beam of electrons from each tip into the surface. The researchers are exploring several ways to record bits using electron beams, including storing tiny electric charges in the surface and eventually using the beams to trigger individual molecular switches.

Near-field optics

Another technology that could take storage to new densities is near-field optics, which uses light to read and write bits similar to but much smaller than those of conventional optical storage devices like CD and DVD drives. Lenses and apertures can focus light beams only so far, limiting how narrow a light beam can be relative to its wavelength. But if a lens or aperture is nearly in contact with a recording surface, light shined through the lens or aperture is confined to a very small area and so can record and read very small bits. Near-field optics has the potential to pack more than a terabit per square inch.

A common near-field optical device is the solid-immersion lens, which is a nearly spherical piece of transparent material with a high refractive index. The refractive index determines the angle at which light waves bend as they pass from one medium to another, and is responsible for the familiar bent-drinking-straw illusion. The spherical shape of the lens bends the light beams inward, concentrating them in a smaller area than would be possible with an ordinary lens.

Holographic Data Storage



Holographic storage

Holographic storage devices have the potential to both hold much more data than magnetic technologies and access it much faster. Holograms are made by bouncing a laser beam off an object and having a second laser beam intersect the reflected light. The laser beams interfere with each other, producing a unique pattern of bright and dark areas that can be captured in storage media like light-sensitive plastics or glass composites. The resulting hologram can be illuminated by shining the second laser beam on the media at the same angle as when the hologram was recorded.

Data is stored holographically by shining a laser beam through a two-dimensional display, usually a liquid crystal display, containing a series of light and dark spots that represent 1s and 0s. Data holograms are two-dimensional pages rather than three-dimensional representations of objects. These holographic pages can be stacked by slightly varying the angle of the second laser beam. The thicker the storage medium, the more pages of data it can hold.

Molecular switches

Storing a bit in a single molecule is about as small as you can get. Certain molecules can be used to store data because they can be switched back and forth between two stable states that can represent the 1s and 0s of digital data. One of these is rotaxane, which contains a thin, thread-like section with a ring that moves freely around it. The ends of the thread section are thicker, preventing the ring from slipping off. Researchers have found ways to move the ring from one end of the thread to the other and the ring will stay where it is placed.

A bit can also be stored in a molecule by changing the molecule's resistance. Some molecules can be made to change their electrical resistances by using a chemical reaction to add or remove electrons or applying a voltage to change the molecule's shape. Researchers have shown that it is possible to read such a bit by applying a low voltage in order to measure the molecule's resistance.

Recent Key Developments

Advances in storage media:

- A method for making magnetic bits using a stamp (Stamp Corrals Tiny Bits, page 9)
- A technique for making virtual boundaries for magnetic bits (Defects Boost Disk Capacity, page 10)

... and 24 more recent key developments.

The full, 38-page version of TRN's Data Storage report also includes 23 in-depth stories and 19 images detailing recent advancements in data storage research.

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