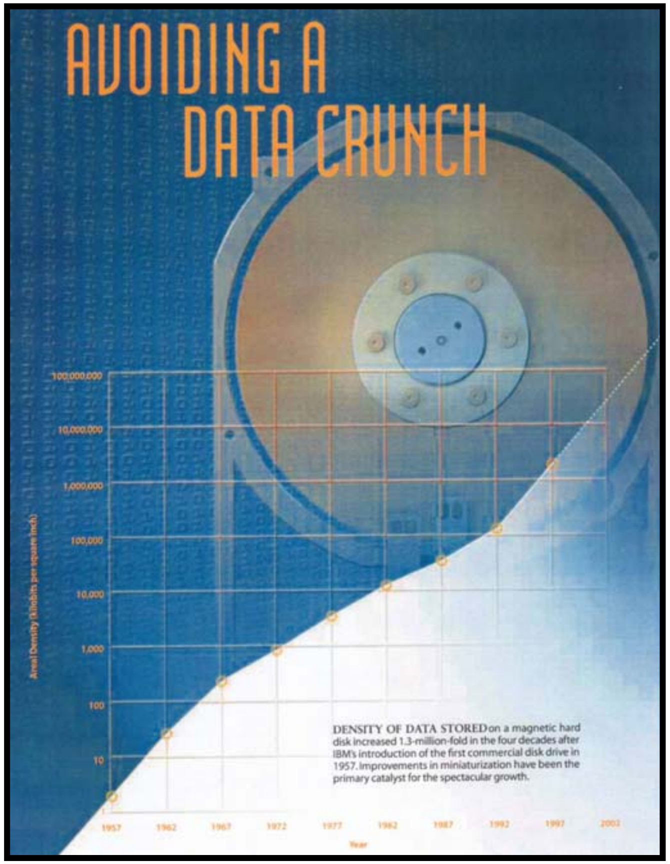
Nanomaterials

Lecture 16: Nanomagnetism

Magnetic Miniaturization

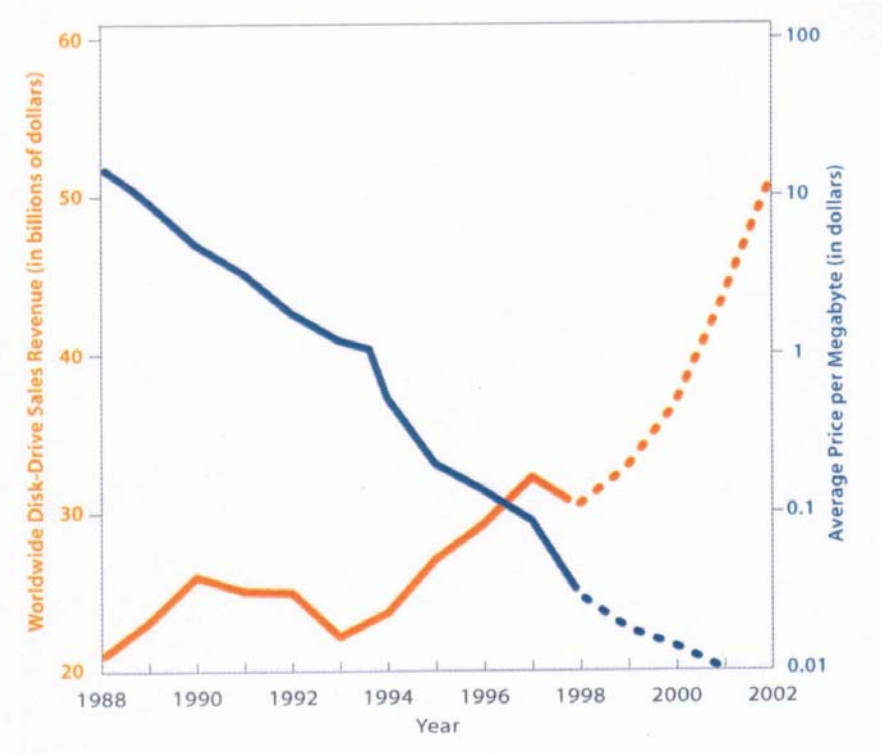


<u>Capacity of magnetic hard disks</u>:

- 1980’s: 30% growth per year
- early 1990’s: 60% growth per year
- late 1990’s: 130% growth per year
- disk capacity doubling every 9 months (twice the pace of Moore’s Law)

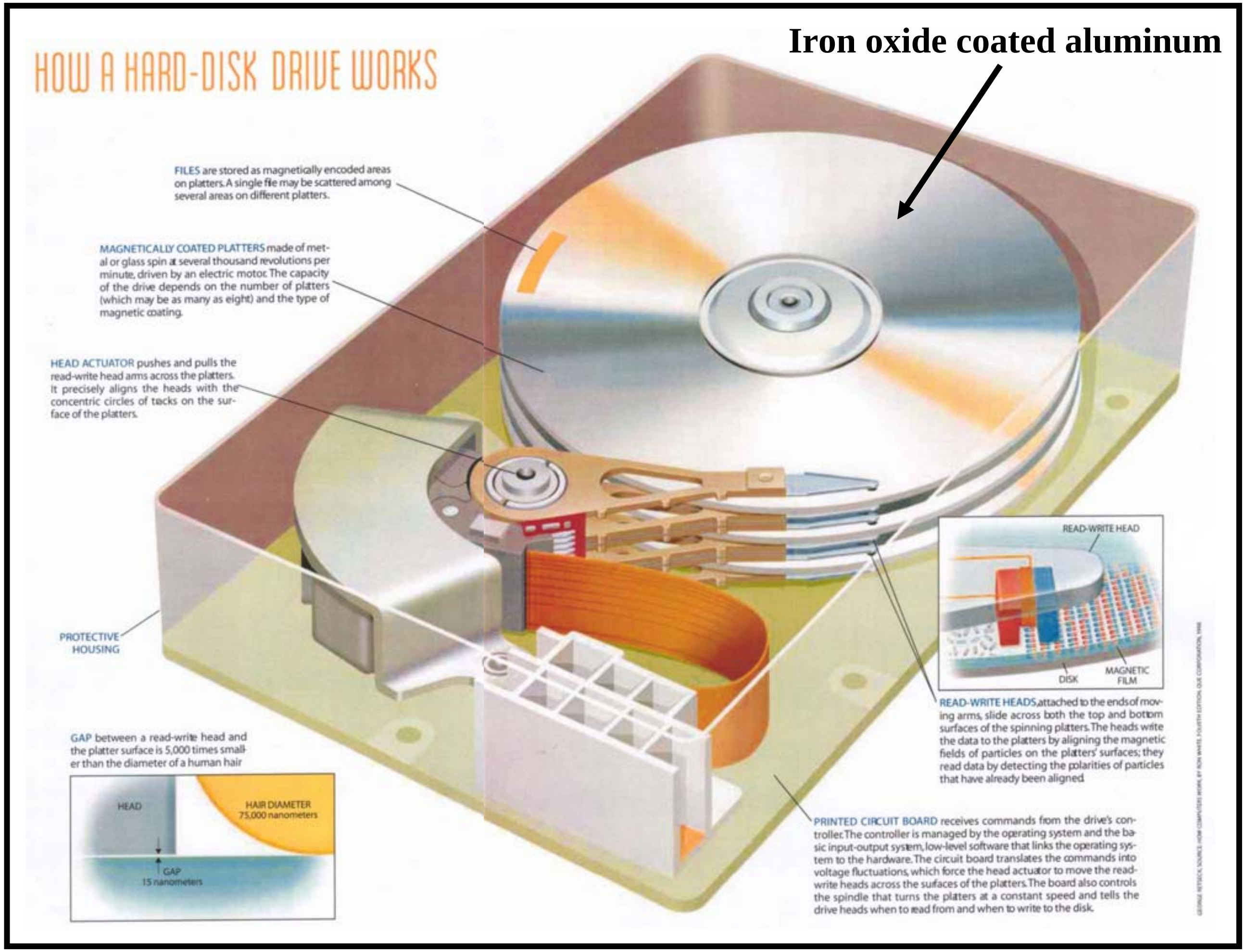
J. W. Toigo, *Scientific American*, **282**, 58 (2000).

Economics of Magnetic Storage



SALES OF HARD-DISK DRIVES have soared as costs per megabyte have plummeted. Sales revenues are expected to grow to $50 billion in 2002.

J. W. Toigo, *Scientific American*, **282**, 58 (2000).



J. W. Toigo, *Scientific American*, **282**, 58 (2000).

Limitations of Nanomagnetic Storage

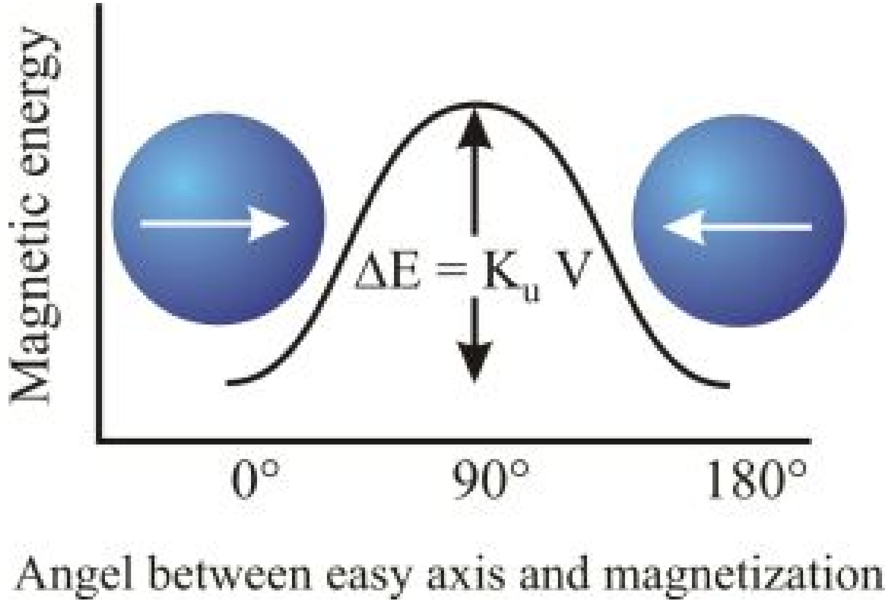
(1) Superparamagnetic effect (SPE) → at the nanoscale, the magnetization energy becomes comparable to ambient thermal energy → bits become susceptible to random flipping

(2) Track width → currently: 20,000 tracks/inch
→ at 150,000 tracks/inch, each track will be ~170 nm wide
→ difficult for heads to follow (requires secondary actuator)

(3) Access speed → at speeds greater than 10,000 revolutions/minute, hard disks emit noticeable audible noise

(4) Read head sensitivity → improved by giant magnetoresistance

Superparamagnetic Effect (SPE)

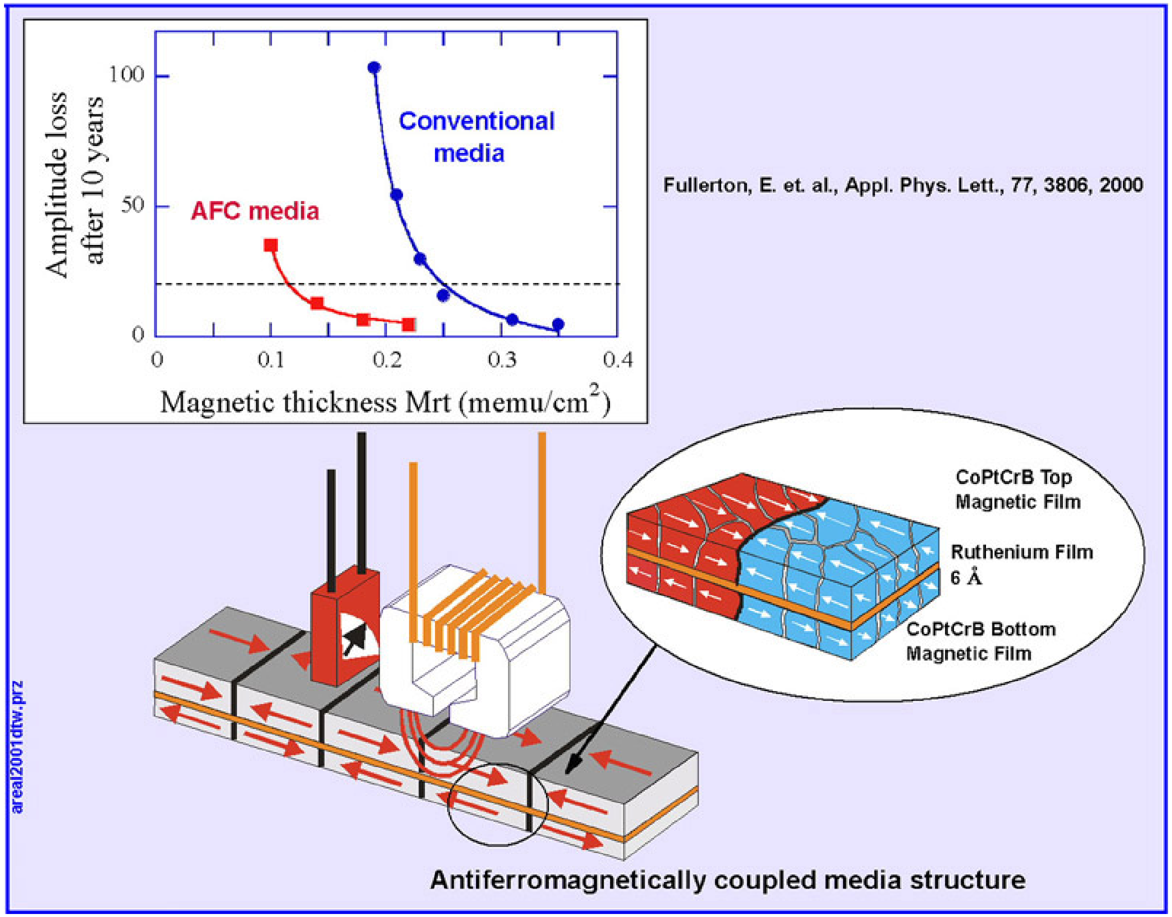


K_u is the magnetic anisotropy

V is the bit volume

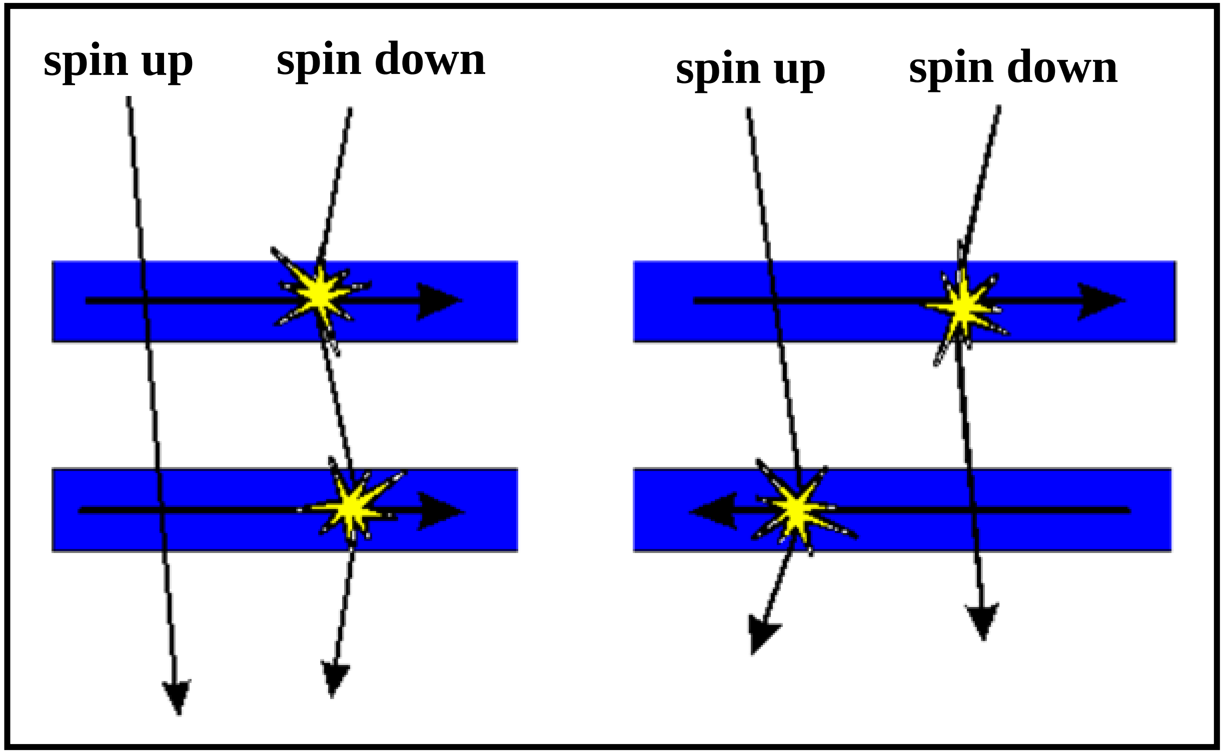
http://idefix.physik.uni-konstanz.de/albrecht/home.htm

Antiferromagnetically Coupled (AFC) Media Structure

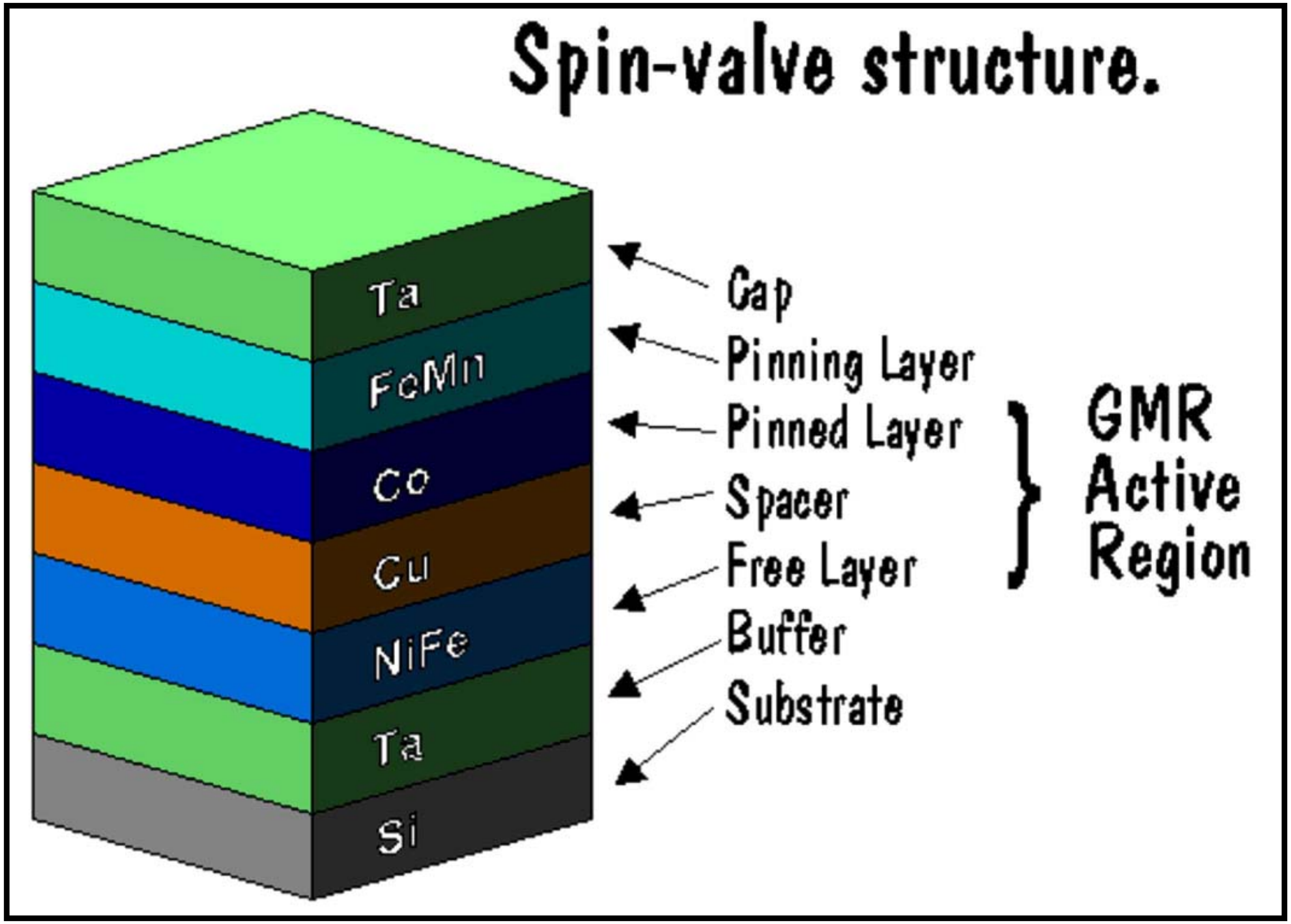


http://www.hitachigst.com/hdd/research/storage/adt/afc1.html

Giant Magnetoresistance (GMR)

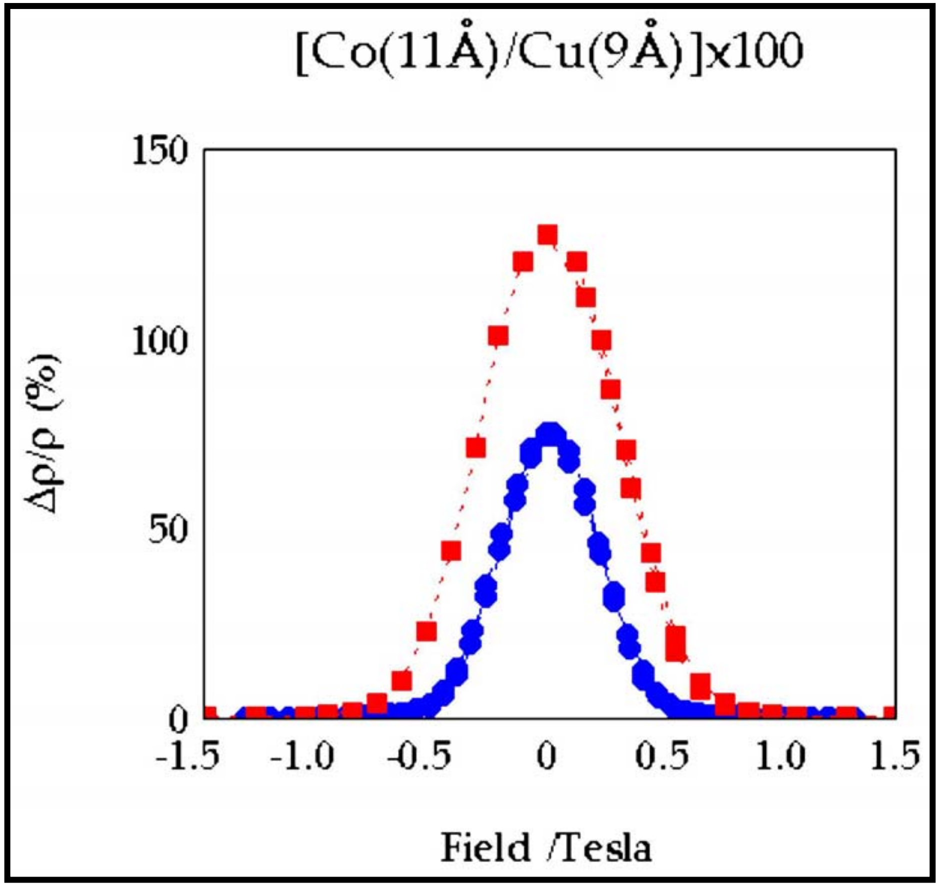


http://www.stoner.leeds.ac.uk/research/gmr.htm



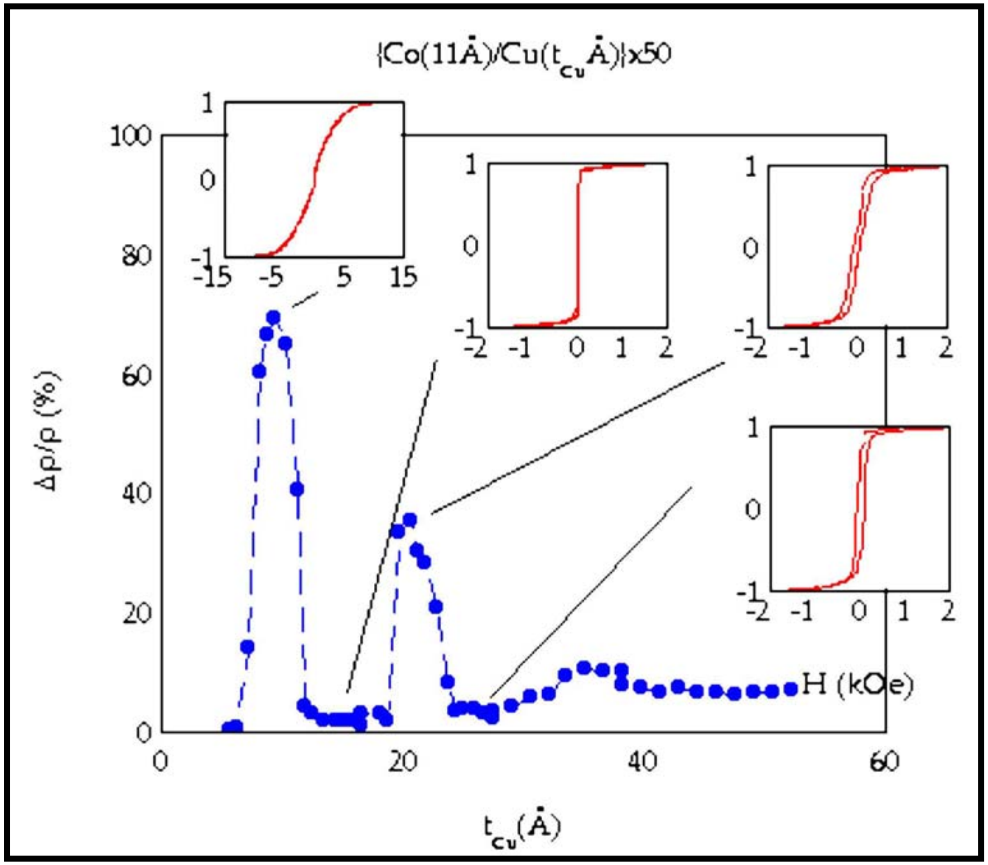
http://www.stoner.leeds.ac.uk/research/gmr.htm

GMR Field Dependence



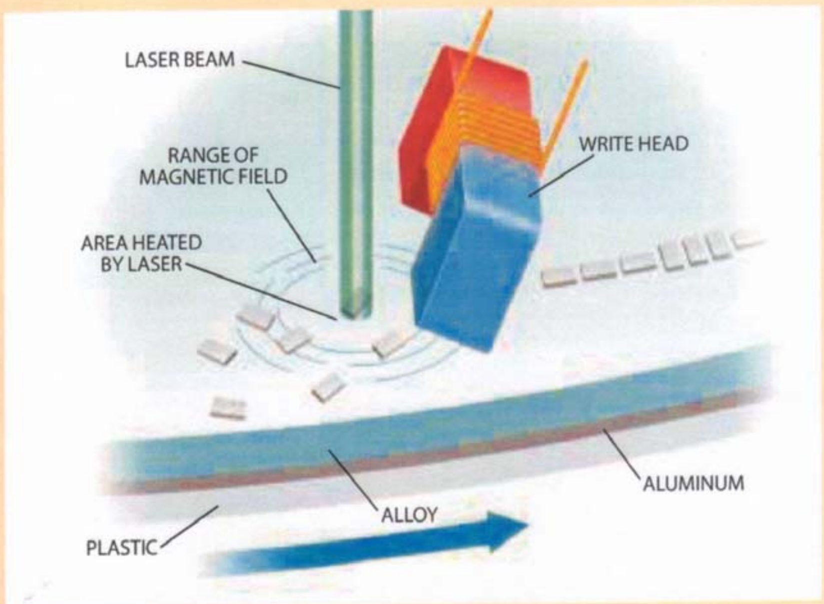
http://www.stoner.leeds.ac.uk/research/gmr.htm

GMR Spacer Thickness Dependence



http://www.stoner.leeds.ac.uk/research/gmr.htm

Using “Hard” Magnetic Materials

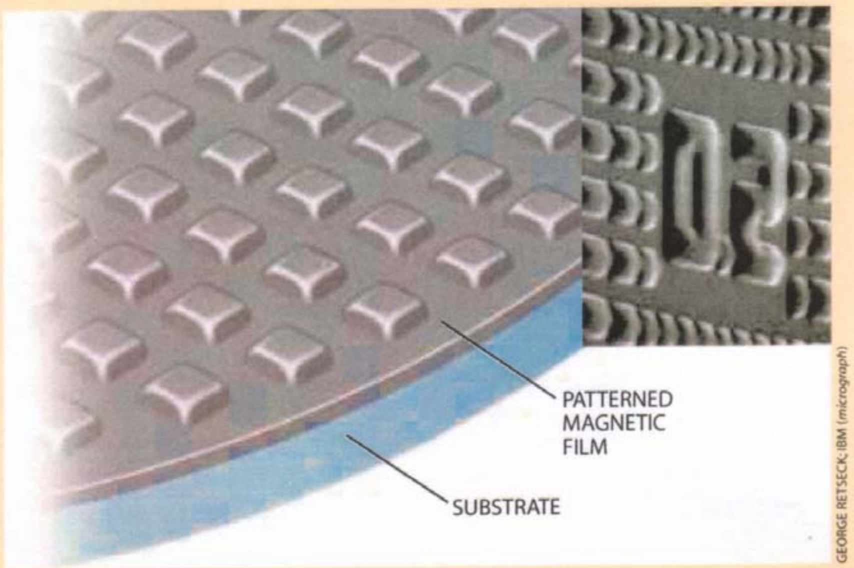


MAGNETO-OPTICAL DRIVE heats a spot with a laser, loosening magnetic crystals so that they can be reoriented with a magnetic field. This basic concept has been difficult to miniaturize because the laser must avoid accidentally heating—and thus possibly destroying—previously stored data. One solution is to manufacture a disk with grooves between concentric tracks of data to block heat from flowing between the tracks. To read the information, Seagate Technology is considering the use of a two-tier system in which the data are stored in tracks on a lower level. When the data are to be read out, a laser heats a section of a track in the lower layer. The heating induces magnetic coupling that transfers the data to the upper level of the disk, where they can be read out in the absence of interfering fields from adjacent tracks.

Materials like Fe/Pt or Co/Sm are more resistant to SPE but are also more difficult to magnetize → use a laser to soften materials during write steps

J. W. Toigo, *Scientific American*, **282**, 58 (2000).

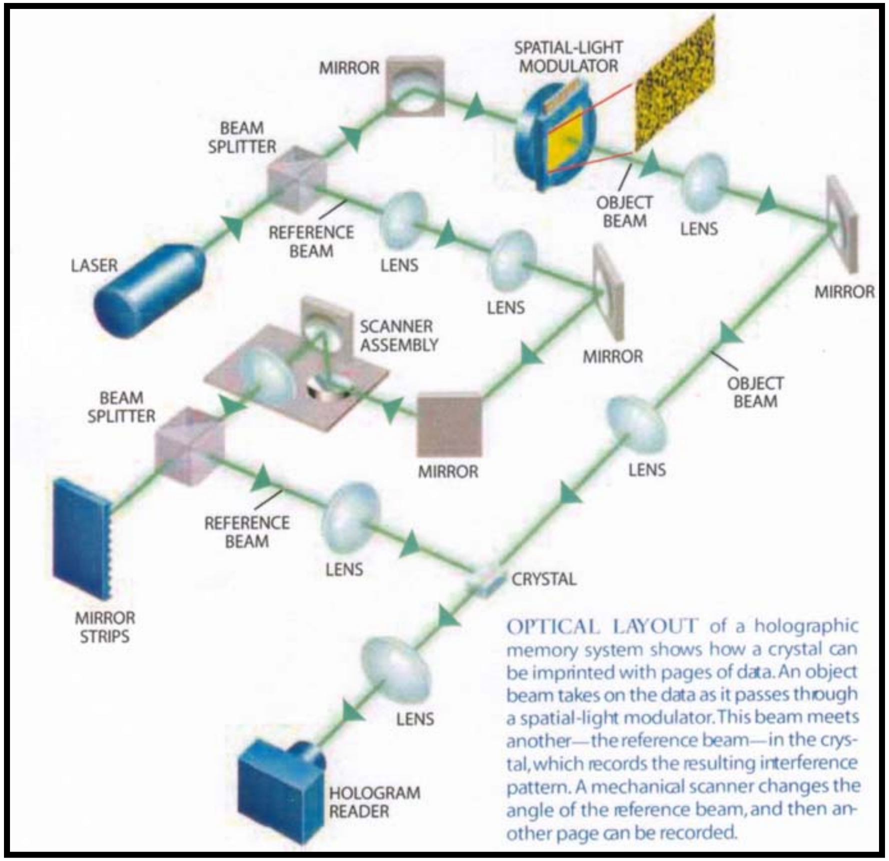
Lithographically Patterned Hard Disks



"MESAS AND VALLEYS" of a future magnetic disk could help manufacturers avoid the superparamagnetic effect, in which closely packed bits in the magnetic media interfere with one another. In this patterned approach, the problem is circumvented by segregating each bit in its own mesa. The difficulty is in making the mesas small enough: they would have to be around eight nanometers across or smaller in order to achieve the kind of densities that developers are seeking. IBM has been able to build such structures with feature sizes as small as 0.1 and 0.2 micron (*inset*), or 100 and 200 nanometers.

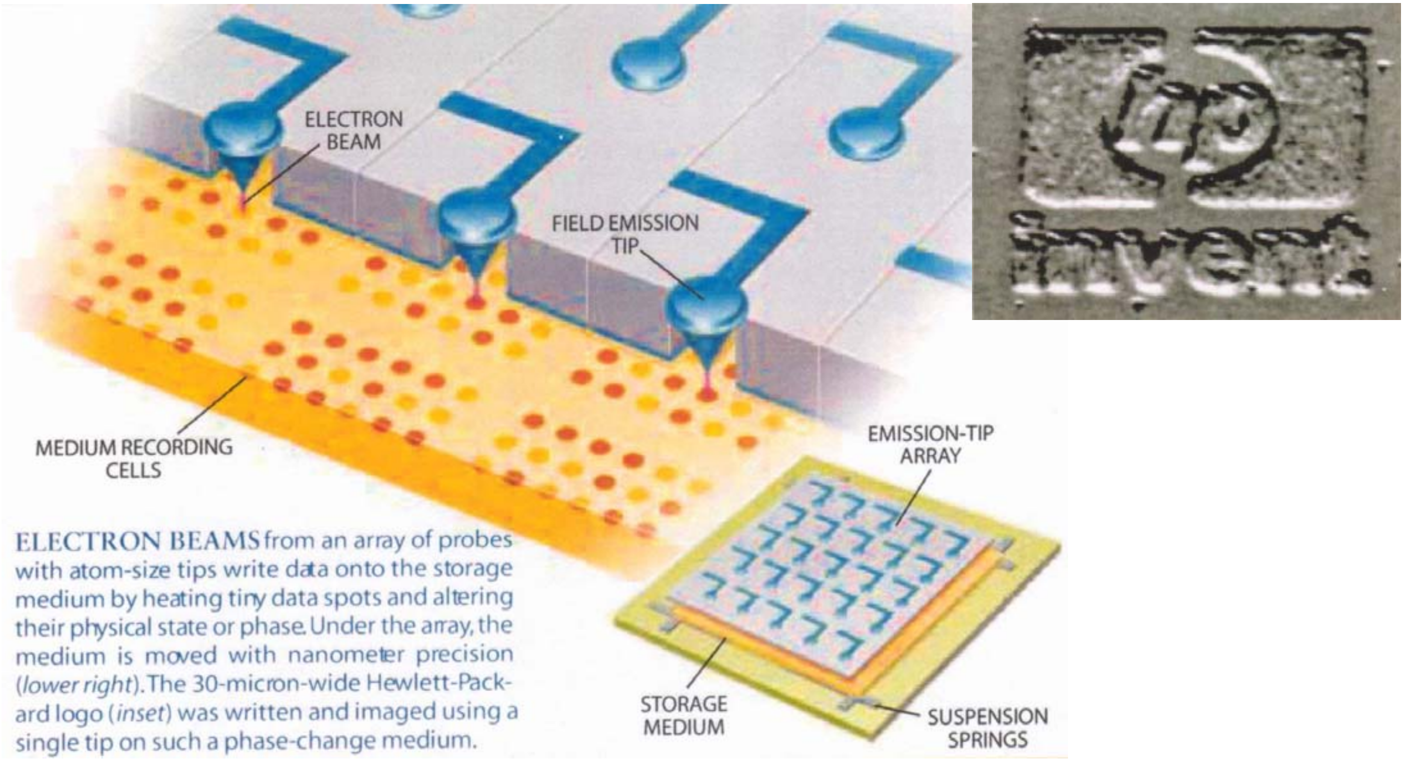
J. W. Toigo, *Scientific American*, **282**, 58 (2000).

Alternative Memories: Optical Storage



J. W. Toigo, *Scientific American*, **282**, 58 (2000).

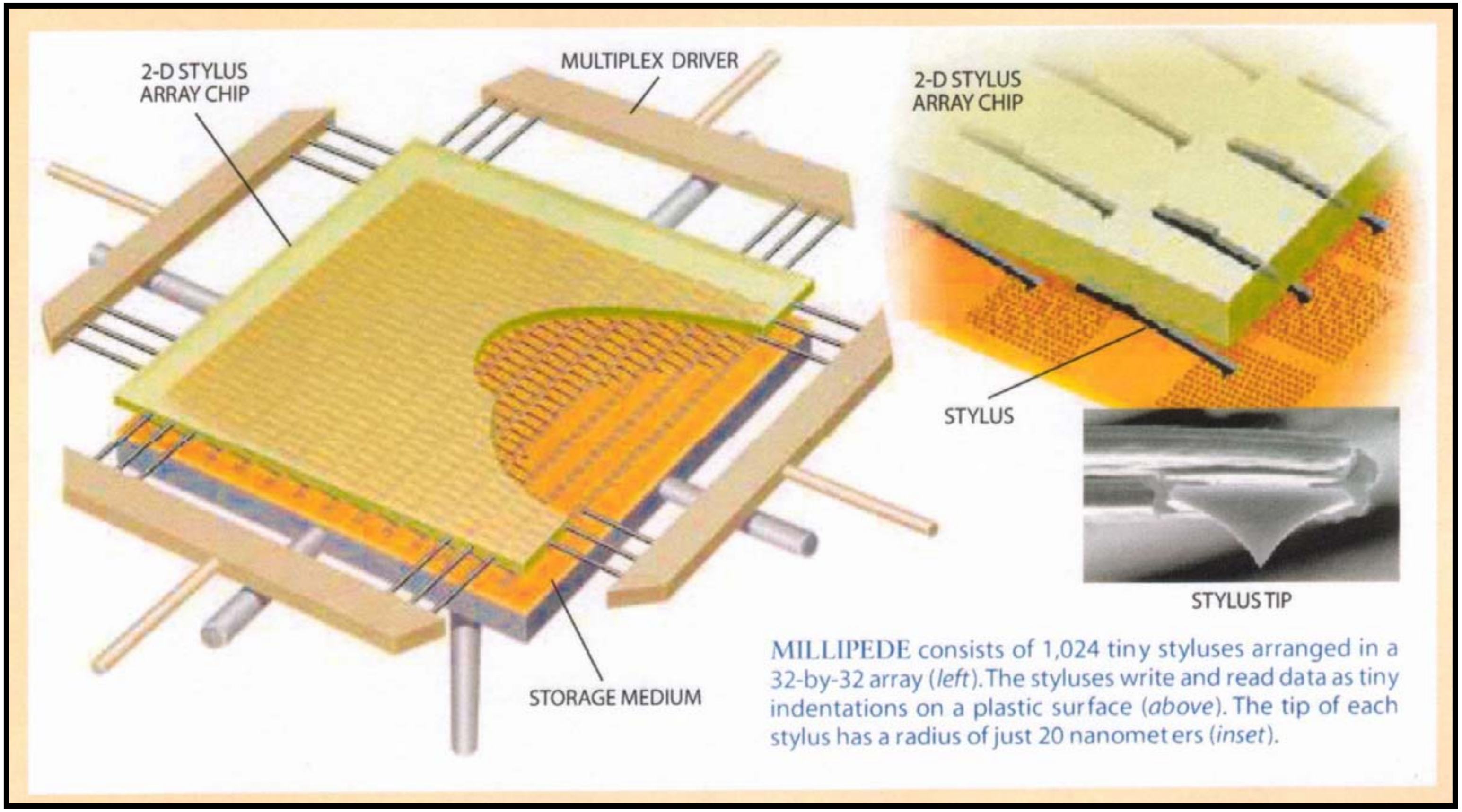
Alternative Memories: E-Beam Arrays



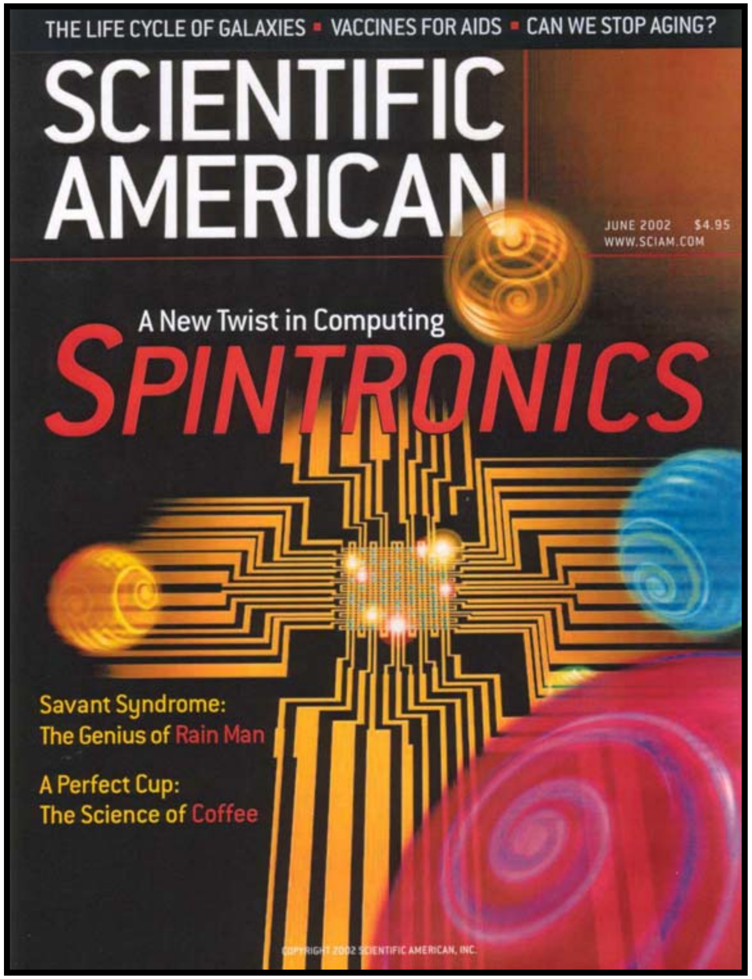
ELECTRON BEAMS from an array of probes with atom-size tips write data onto the storage medium by heating tiny data spots and altering their physical state or phase. Under the array, the medium is moved with nanometer precision (*lower right*). The 30-micron-wide Hewlett-Packard logo (*inset*) was written and imaged using a single tip on such a phase-change medium.

J. W. Toigo, *Scientific American*, **282**, 58 (2000).

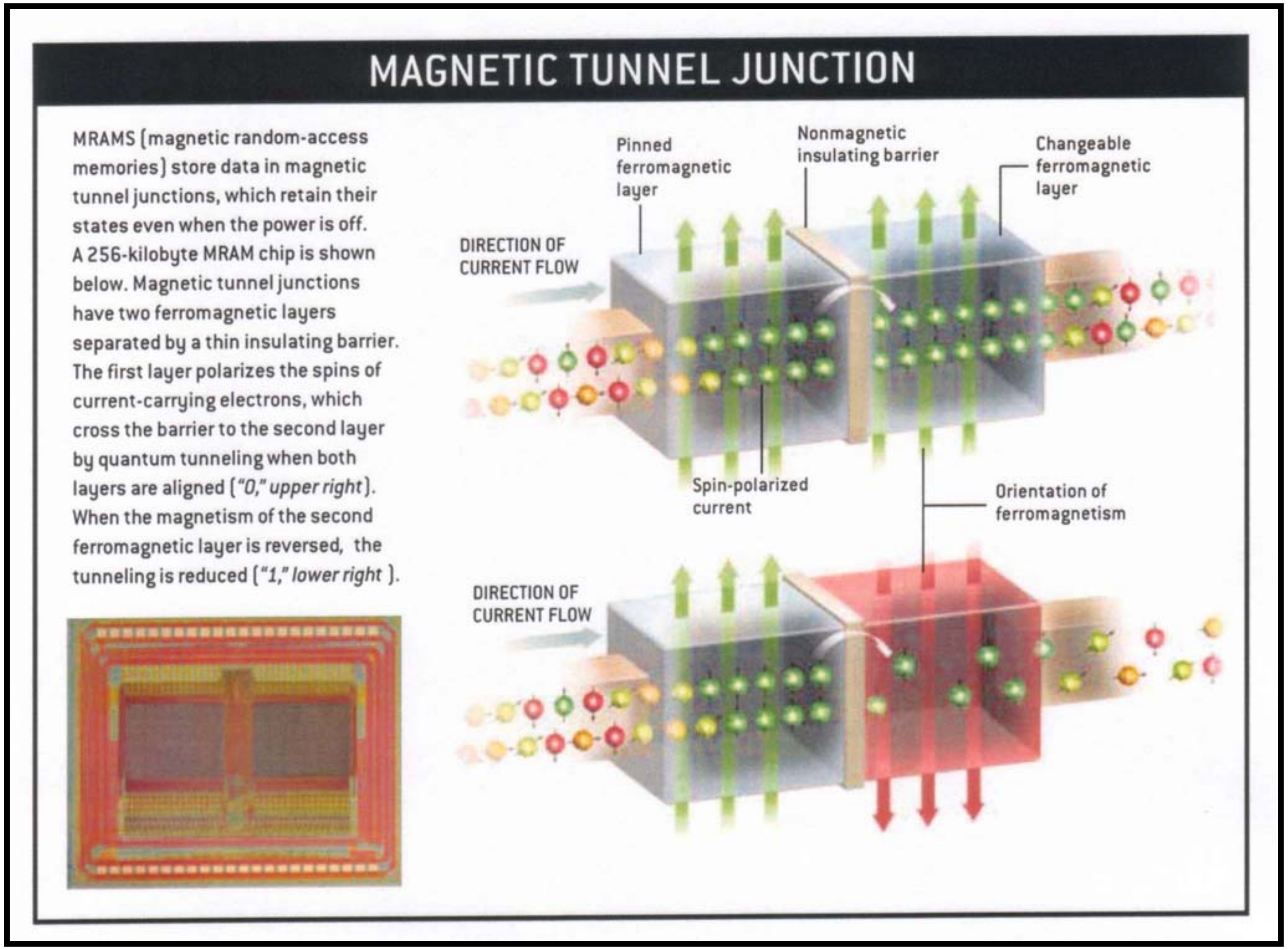
Alternative Memories: Millipede



J. W. Toigo, *Scientific American*, **282**, 58 (2000).

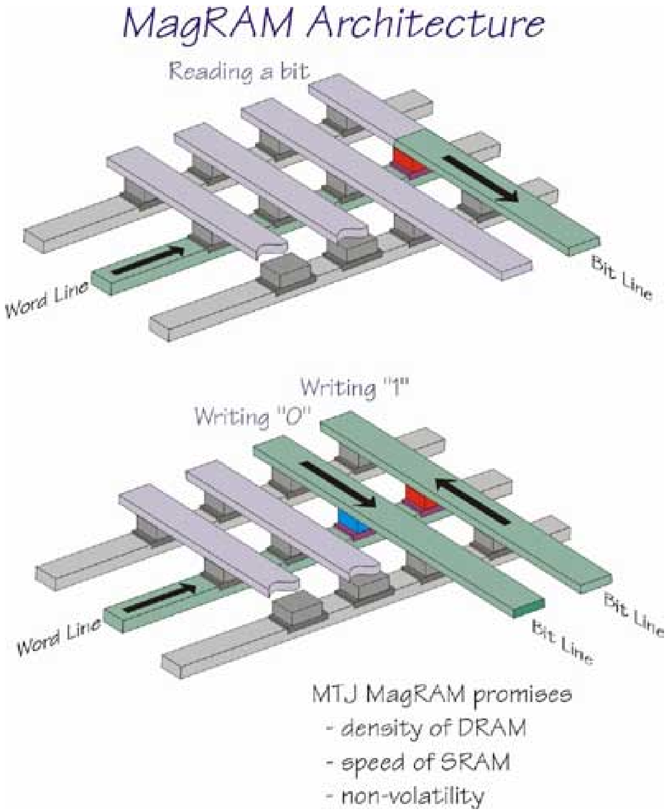


D. D. Awschalom, *et al.*, *Scientific American*, **284**, 67 (2002).

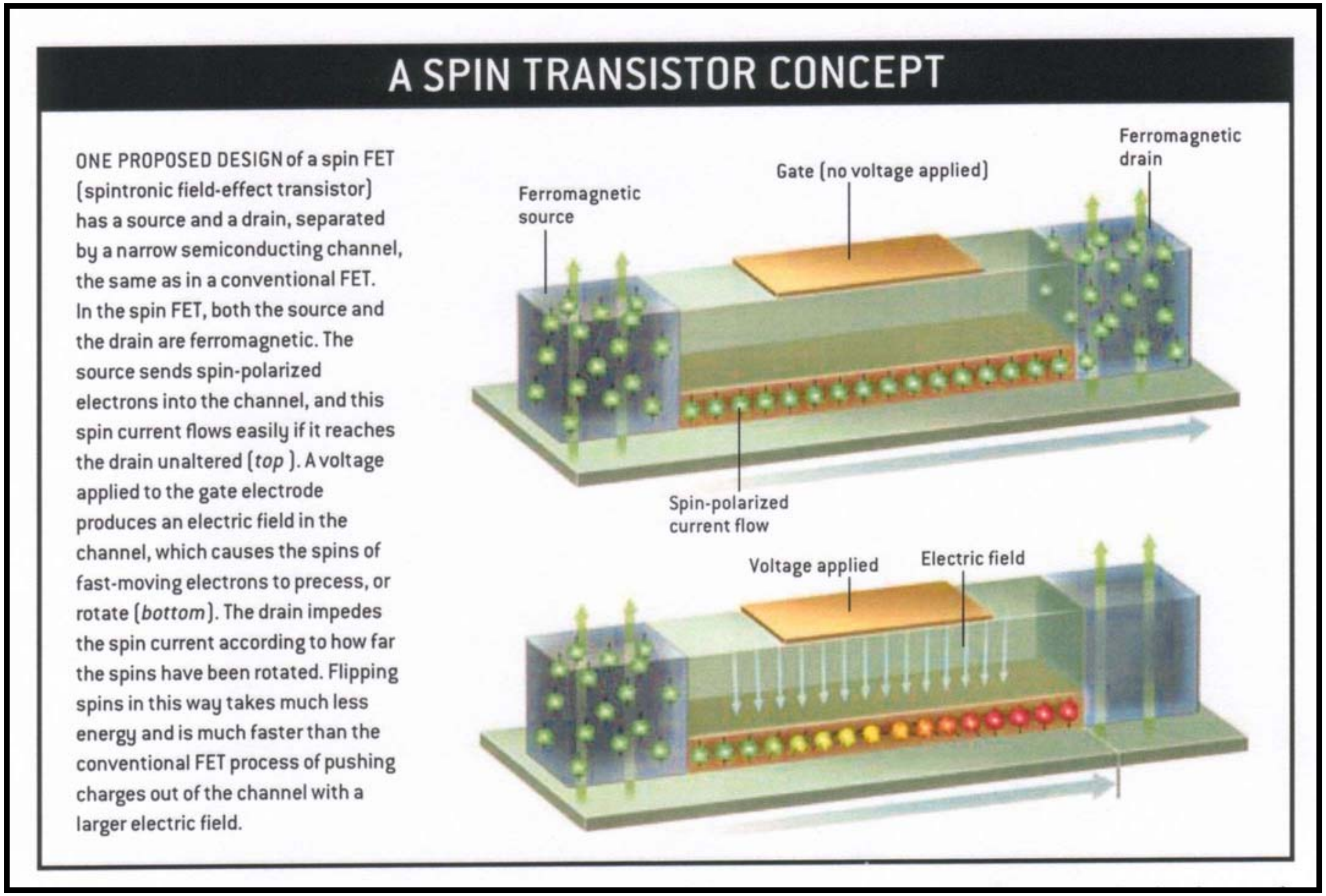


D. D. Awschalom, *et al.*, *Scientific American*, **284**, 67 (2002).

Magnetic RAM



http://www.research.ibm.com/resources/news/20001207_mramimages.shtml


A SPIN TRANSISTOR CONCEPT

ONE PROPOSED DESIGN of a spin FET (spintronic field-effect transistor) has a source and a drain, separated by a narrow semiconducting channel, the same as in a conventional FET. In the spin FET, both the source and the drain are ferromagnetic. The source sends spin-polarized electrons into the channel, and this spin current flows easily if it reaches the drain unaltered (*top*). A voltage applied to the gate electrode produces an electric field in the channel, which causes the spins of fast-moving electrons to precess, or rotate (*bottom*). The drain impedes the spin current according to how far the spins have been rotated. Flipping spins in this way takes much less energy and is much faster than the conventional FET process of pushing charges out of the channel with a larger electric field.

D. D. Awschalom, *et al.*, *Scientific American*, **284**, 67 (2002).

Semiconductor Spintronics

In addition to the SPIN FET, a number of other spin polarized semiconductor devices have been proposed:

(1) Spin polarized p-n junctions
(2) Spin polarized LEDs
(3) Photo-induced ferromagnetism
(4) Spin polarized BJTs

All of these technologies depend upon development in materials:

(1) Dilute Magnetic Semiconductors, (2) Ferromagnetic Contacts, (3) Spin Detection Strategies, etc.

Nanomagnetic Logic

Room Temperature Magnetic Quantum Cellular Automata

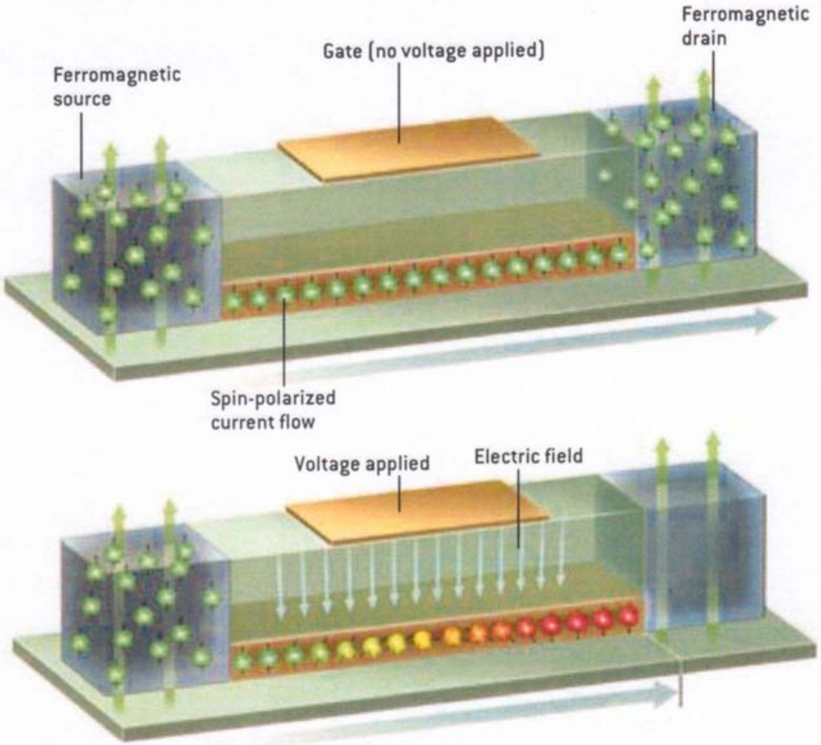
R. P. Cowburn* and M. E. Welland

All computers process information electronically. A processing method based on magnetism is reported here, in which networks of interacting submicrometer magnetic dots are used to perform logic operations and propagate information at room temperature. The logic states are signaled by the magnetization direction of the single-domain magnetic dots; the dots couple to their nearest neighbors through magnetostatic interactions. Magnetic solitons carry information through the networks, and an applied oscillating magnetic field feeds energy into the system and serves as a clock. These networks offer a several thousandfold increase in integration density and a hundredfold reduction in power dissipation over current microelectronic technology.

R. P. Cowburn and M. E. Welland, *Science*, **287**, 1466 (2000).

A SPIN TRANSISTOR CONCEPT

ONE PROPOSED DESIGN of a spin FET (spintronic field-effect transistor) has a source and a drain, separated by a narrow semiconducting channel, the same as in a conventional FET. In the spin FET, both the source and the drain are ferromagnetic. The source sends spin-polarized electrons into the channel, and this spin current flows easily if it reaches the drain unaltered (*top*). A voltage applied to the gate electrode produces an electric field in the channel, which causes the spins of fast-moving electrons to precess, or rotate (*bottom*). The drain impedes the spin current according to how far the spins have been rotated. Flipping spins in this way takes much less energy and is much faster than the conventional FET process of pushing charges out of the channel with a larger electric field.



D. D. Awschalom, *et al.*, *Scientific American*, **284**, 67 (2002).

Semiconductor Spintronics

In addition to the SPIN FET, a number of other spin polarized semiconductor devices have been proposed:

(1) Spin polarized p-n junctions
(2) Spin polarized LEDs
(3) Photo-induced ferromagnetism
(4) Spin polarized BJTs

All of these technologies depend upon development in materials:

(1) Dilute Magnetic Semiconductors, (2) Ferromagnetic Contacts, (3) Spin Detection Strategies, etc.

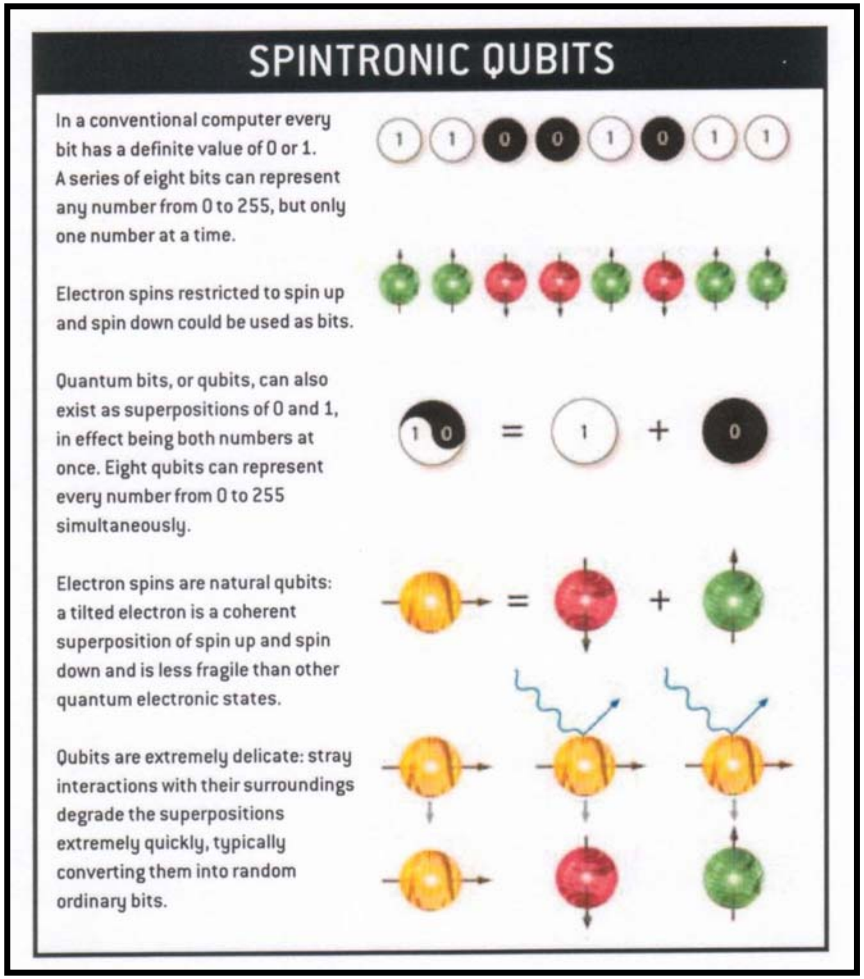
Nanomagnetic Logic

Room Temperature Magnetic Quantum Cellular Automata

R. P. Cowburn* and M. E. Welland

All computers process information electronically. A processing method based on magnetism is reported here, in which networks of interacting submicrometer magnetic dots are used to perform logic operations and propagate information at room temperature. The logic states are signaled by the magnetization direction of the single-domain magnetic dots; the dots couple to their nearest neighbors through magnetostatic interactions. Magnetic solitons carry information through the networks, and an applied oscillating magnetic field feeds energy into the system and serves as a clock. These networks offer a several thousandfold increase in integration density and a hundredfold reduction in power dissipation over current microelectronic technology.

R. P. Cowburn and M. E. Welland, *Science*, **287**, 1466 (2000).



D. D. Awschalom, *et al.*, *Scientific American*, **284**, 67 (2002).