Tiny Grains and Giant Magnetoresistance: Numerical Micromagnetics

FEATURED:

H. Neal Bertram and Christian Seberino, University of California, San Diego

Data, data, data. Never before have so many wanted so much so fast. Not only the scientist, but also nearly everyone stores ever-increasing volumes of data, and everyone wants to look at more of it faster. "Magnetic recording on rigid computer discs is at the core of the information revolution," says Neal Bertram of the Center for Magnetic Recording Research (CMRR) at UCSD.

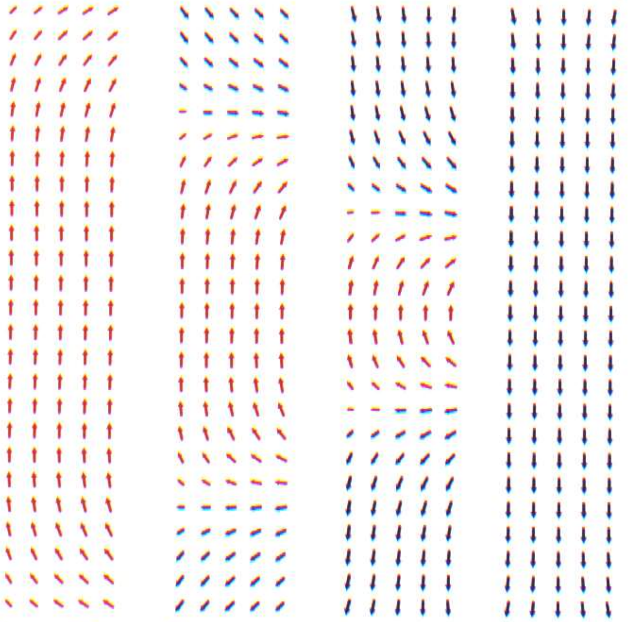

FIGURE 1: SINGLE-PARTICLE BEHAVIOR

The evolution of magnetization in a single particle from a saturated state along the particle length axis to the opposite direction, with the application of a suitable (coercive) reverse field.

The magnetic information storage and retrieval industry reports annual sales of nearly $60 billion. Storage densities (now 1-2 gigabits per square inch) and data rates (now around 200 MHz) are advancing by about 40 to 60 percent annually, according to Bertram. "At the high end, we want to access tens of gigabits in a few milliseconds from discs and terabytes in a few minutes from mass storage," Bertram says. His own basic research thus focuses on densities from 10 to 20 gigabits per square inch and data rates of 500 MHz.

Engineers applying research done by the Bertram group have achieved 30-fold increases in storage densities, and the group continues to develop the basis for further advances in storage density and retrieval rates. They simulate the recording media and the transducers used to write and read stored information. Only magnetic recording, Bertram notes, is capable of the high densities and data rates required now and in the near future. (Optical recording, by contrast, is limited to densities set by the wavelength of the light used—ultimately about 2.5 gigabits per square inch with the shortest wavelengths. Data rates are constrained by mechanical limits to about 50 MHz. Optics are also limited by current designs in which read/write beams have access to only one disc surface.)

COMPUTATIONAL PHYSICS OF MAGNETIC RECORDING

All recording media surfaces (disc or tape) are particulate or granular in composition, usually a metallic alloy composition. Microscopic granular structures must be sized optimally to sustain the large *coercivities* (magnetic field strengths) required to write and stabilize recorded information. The dynamic processes of recording or reading bits follow a damped, coupled gyromagnetic system of equations, describing a parallel evolution of each grain magnetization.

"Our *numerical micromagnetics* is especially computationally intensive because magnetic interactions are inherently long-range," Bertram says, "and to do reasonable simulations we must represent several thousand grains." Magnetostatic interaction calculations scale as the square of the number of grains (N^2). For modeling that can be performed with periodic arrays, FFT techniques reduce computation time to $N\ln N$. For nonperiodic systems, multipole expansion techniques can reduce the time to an order between N and $N\ln N$.

"All these types of computation are inherently parallel," Bertram says. "Over the years, we've used all of SDSC's parallel machines, and we are now stretching the capacities of the 256-processor CRAY T3E with appropriately optimized algorithms."

SINGLE-GRAIN BEHAVIOR

To record a *1* on a disc or tape it is necessary to reverse the direction of the magnetization in a bit cell. Bertram and graduate student Chris Seberino have succeeded in simulating the detailed process of magnetization reversal in a single elongated iron tape particle, 20 x 20 x 100 nanometers in size (Figure 1).

They have shown that magnetization switching occurs initially by the rotation of the magnetization at the particle ends, and the reversal region occupies a volume approximately the particle width cubed. After the end magnetizations have rotated beyond 90 degrees, the domain wall created by the localized reversal propagates from the ends to the interior until reversal is complete. The initial rotations occur in about 1 nanosecond and, for a 5:1 ellipticity particle, the subsequent wave propagation takes about 12 nanoseconds. The reversal of a particle with discretization cells sized, in this case, at about 2 nm (5000 cells) involved N^2 direct interaction computations per step and takes about an hour on the T3E.

ADVANCED TRANSDUCERS

Virtually all current disc drives use the magnetoresistance (MR) phenomenon in the playback of recorded data. The magnetic fields produced by the recorded *1*'s rotate the magnetization in a thin-film sensor as the bits pass by. This sensor has a "cross-track" current applied: a change in magnetization angle with respect to the current direction changes the resistance and hence a monitoring voltage. Typically, replay of a single recorded bit will produce a voltage change of about 120 microvolts per micron of track width.

Bertram and Seberino have been simulating advanced "giant MR" devices that rely on the relative magnetization direction between multilayers of films. One variety of device has dual layers and is called a spin valve. Other designs use granular films, where the MR depends on the relative magnetization between adjacent grains (nearest-neighbor grain magnetization correlations). Figure 2 illustrates the simulation of such a design.

FUTURE DIRECTIONS

Bertram has begun research on the next step, the recording of ultrahigh densities, on the order of 100 gigabits per square inch. Key issues are the stability of recorded information and the ability to achieve extremely high data rates, in the 1–2 GHz range. At such densities, grains must be tiny to achieve required system performance. "But as grains decrease in size, their magnetic energy decreases, and eventually it is possible for thermal energy, which acts like a random field, to reverse the magnetization," Bertram says. A typical specification is that data be recoverable after 10 years' storage at room temperature.

The group has also begun simulations of recording transducers that include the effect of conductive losses. "Micromagnetic simulations that include thermal excitations or conductive losses are extraordinarily time-consuming, because extremely short time intervals must be used," Bertram says. "We will focus on developing the most efficient algorithms for both problems."

At CMRR the goal is to resolve fundamental issues in the development of advanced magnetic recording systems. The center is funded by a combination of government and industrial support. Its five large research groups concentrate on signal processing, magnetic materials, mechanics, instrumentation, and the fundamental physics of the magnetic recording process. *—MM* ◆

FURTHER INFORMATION

CMRR: http://www.ucsd.edu/CMRR

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Bertram, H.N., and J-G. Zhu. Fundamental magnetization processes in thin film recording media, in H. Ehrenreich and D. Turnbull (eds.), *Solid State Physics Review* 46, 271-371 (Academic Press: 1992).

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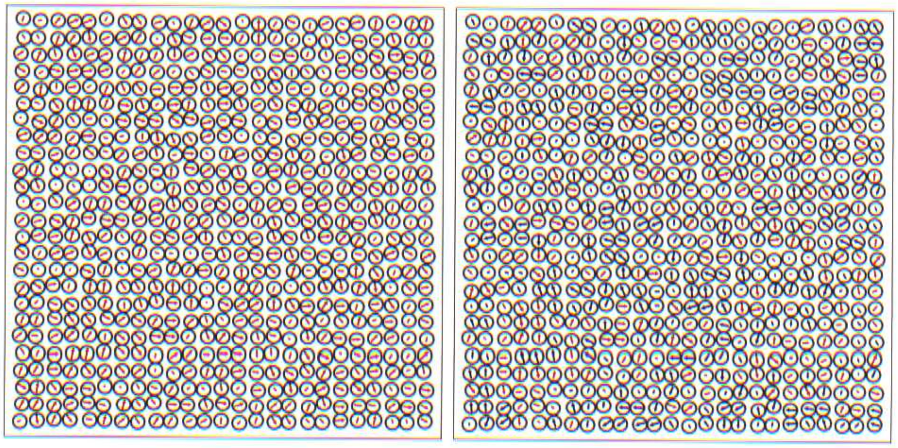

FIGURE 2: GIANT MAGNETORESISTANCE DEVICE

The magnetization of 50-nm spherical grains in one film of a proposed giant magnetoresistance (MR) device for two magnetic states. Left: *In a saturated state, all the grain magnetizations are in virtually the same direction.* Right: *In this state, a field has been applied to make the net magnetization vanish; the grain magnetizations on average are divided equally between opposite directions. The MR is low in the saturated state but high where the net magnetization is zero, owing to magnetic interactions between the grains.*