fly, don't have this mechanism, he says. They ignore rapid variations and use the extra time to gather the redundant information that combats noise. "This is [a] way in which the neural circuits are microengineered for specific purposes," says Laughlin.

Results of this sort reassure physicists that they are on the right track in viewing the visual system as an optimal response to physical limits. Says Bialek: "In the 70s, I thought that the central nervous system was a mess, and physicists shouldn't study it...but now people can do these unbelievably quantitative and reproducible experiments." Adds Barlow, "It's easy when one starts looking at biological tissues to see them as hopelessly inefficient." But as people have probed deeper over the past few years, he says, "it gives us a source of perpetual amazement."

–**Faye Flam**

MATERIALS SCIENCE

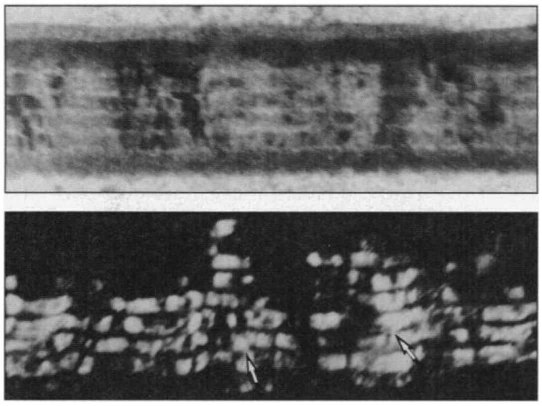
Magnetic Films Get Sensitivity Training

It's easy to get excited about discoveries in high-profile fields with catchy names like "chaos" or "superconductivity," but many other areas of science promise at least as great an impact on our lives yet don't have nearly the same media glamor. Take giant magnetoresistance. That's an inelegant name for a rather elegant physical effect—a change in the electrical resistance of a material when it is placed in a magnetic field. A community of researchers is hoping to make this jawbreaker a small but important part of everyday life, and a paper in this issue of *Science* moves that goal another step closer to reality.

A group at IBM ADSTAR in San Jose, California, has found a way to create materials that show giant magnetoresistance (GMR) at low magnetic fields (see page 1021). The discovery, by Todd Hylton, Kevin Coffey, Michael Parker, and Kent Howard, could greatly increase the capacity of magnetic data storage devices, such as disk drives, by making it feasible to read and write smaller bits of magnetically coded information. "A lot of people have been trying to do this," says John Barnard, a materials scientist at the University of Alabama in Tuscaloosa. The work is a "proof of principle," he says, because it shows it is possible to create GMR at fields low enough to be practical.

Though it isn't a staple of popular science books or newspaper accounts, GMR has been the hottest area of magnetic materials research almost since its discovery 5 years ago. Part of the reason has been excitement over a new physical phenomenon, but part of it is GMR's commercial promise. In fact, a first cousin of GMR—ordinary magnetoresistance (MR)—is already being used in some high-performance computer data storage devices. Most of the "read" heads in today's disk drives depend on induction—the creation of an electrical current by a changing magnetic field—but induction heads are fast approaching their physical limits, where the bits of data can get no smaller and still be read. MR, an effect created in certain magnetic metals when a magnetic field aligns the spins of the conduction electrons and affects the material's resistance to a current, yields heads that can read smaller bits than conventional heads can.

But MR has limits of its own. The resistance of typical MR materials generally changes by no more than about 4%, and by only 1% to 2% in the practical, mass-produced form used in read heads. If the resistance varied more, the magnetic bits could be made still smaller. So companies like IBM were excited 5 years ago when researchers at



MICHAEL ANDREW PARKER/IBM ADSTAR

Slices of the sandwich. Electron micrographs of the new magnetoresistive material show continuous magnetic layers *(light bands in top image)* that break up *(arrows)* after annealing.

the Université de Paris-Sud reported a more dramatic effect, which they called giant magnetoresistance: resistance changes of up to 50% at a temperature of 4.2 K.

While MR is a "bulk effect" that appears in materials without specific atomic-scale structures, GMR arises in very structured materials consisting of atoms-thick layers of magnetic materials, such as iron or nickel, interspersed with layers of nonmagnetic materials, such as silver. Each of the magnetic layers can be thought of as a little sliver of a bar magnet, with the magnetizations of alternating magnetic layers pointing in opposite directions. When electrons of an electric current pass through one of these layers, half of them find it easy going and half are slowed down, depending on the direction of their spins. When they pass into the next layer, the roles are reversed. The upshot is that none of the electrons has an easy time passing through the entire layered structure, and the resistance is relatively high.

Applying a magnetic field to this layered structure, however, causes the magnetizations to line up, so that half of the electrons get a smooth ride through the whole material. Although the other half finds it even tougher going, the end result is that the total resistance drops. Since the phenomenon was first observed, researchers have made GMR materials whose resistance changes by as much as 65% at room temperature.

The problem is that achieving such dramatic resistance changes takes very high magnetic fields—typically 250 oersteds or more, or at least 500 times Earth's magnetic field—perhaps because the opposite magnetizations of the layers tend to "couple," or lock together, says Hylton. These fields are too high to be practical for magnetic data storage. The IBM ADSTAR group has now managed to create giant magnetoresistance in much smaller magnetic fields—only 5 to 10 oersteds. So far they see a resistance change of only 4% to 6%, but the group hopes to keep improving on it.

To achieve the effect, the researchers created alternating layers of nickel-iron and silver only a few nanometers thick, then "annealed" the material by quickly heating and cooling it. The GMR appears only after annealing, so the group members believe this step holds the key to GMR at low magnetic fields. The reason is still unclear, but the group offers a hypothesis: When the material is heated, the silver starts to diffuse into the nickel-iron layer, working its way into the cracks between the grains of nickel-iron. This creates a collection of disk-like islands of nickel-iron in a three-dimensional silver sea, with the islands in alternate layers having opposing magnetizations. The shape and size of these islands, Hylton says, make it easier for relatively weak magnetic fields to align their magnetizations, perhaps because the magnetic coupling between islands is weaker than it is between intact layers.

It's too soon to know for sure whether the GMR films made by this technique can be adapted to the high-volume production necessary for electronic equipment, but Hylton and his colleagues are optimistic that they can be. At the University of Alabama, Barnard agrees that some variant of the IBM ADSTAR technique—if not this particular material—should find its way to commercial application. One way or another, GMR may overcome the handicap of its name and find a place in the technological spotlight.

–**Robert Pool**