MATERIALS SCIENCE

New Superconductor Stands Up to Magnetic Fields

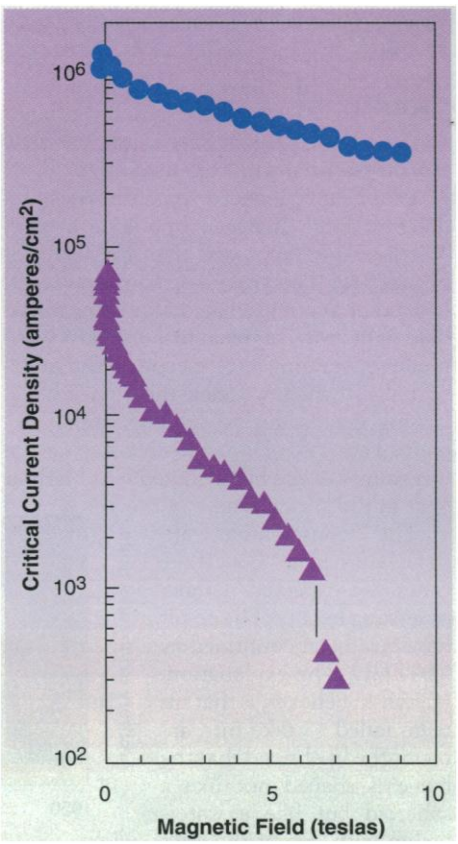
SAN FRANCISCO—For high-temperature superconductors (HTS), long touted as electrical superheroes, magnetic fields have been the equivalent of kryptonite. HTS materials are capable of carrying huge electrical currents without resistance. But put them in a powerful magnetic field and their current-carrying ability plummets, threatening to keep them out of applications such as magnetic resonance imaging (MRI) machines and electric motors. But now, materials scientists are learning how to fight back.

Until recently, the only way to combat the magnetic fields was to chill HTS materials down to around 20 degrees kelvin, a level of cold hardly worthy of the name "high temperature" and requiring expensive coolants like liquid helium. But at the Materials Research Society meeting held here last month, researchers from Los Alamos National Laboratory reported making a flexible superconducting tape that stands up to high magnetic fields at a balmy 77 K. The tape can pack a powerful electrical punch—carrying more than one million amperes of electrical current per square centimeter of cross section (A/cm^2). "This is a real winner," says Paul Grant, a high-temperature superconductivity specialist for the Electric Power Research Institute in Palo Alto, California. "At 77 degrees nothing can come close to this." HTS magnets and motors made with this material would likely still be cooled to near 47 K to ensure uninterrupted operation even if the temperature made an unexpected rise, says Greg Yurek, president of American Superconductor Corp. in Westborough, Massachusetts. But any increase in operating temperature translates into a big savings in cooling costs, he adds.

But while the performance of the new materials is impressive, it's not clear whether the technique can be scaled up to industrial levels. The Los Alamos group has provided only a sketchy outline of their tape production method, as they are trying to license it to a company. What other scientists have seen, however, has led some to wonder whether part of the process—a material-deposition method—is too slow for the industrial world. But if it is, another team at the meeting demonstrated a competing technique that's potentially faster.

Researchers have been pursuing HTS wires for use in coils in magnets and electric motors because they can make powerful magnets with less material. Such wires need to succeed on two counts. First, when laid down as a wire or tape, the tiny crystal grains that make up HTS materials must maintain near-perfect alignment; misaligned grains impede current flow. Second, the material has to be able to prevent powerful external magnetic fields from penetrating its core, because magnetic fields consume energy and destroy superconductivity.

Scientists have been able to make HTS wires with bismuth- and thallium-based ceramics, as the materials tend to have good grain alignment. But these wires can withstand only modest magnetic fields unless they are cooled way down. Bismuth-based HTS magnets, for example, lose superconducting performance in fields above 0.6 tesla at 77 K, and today's MRI machines routinely generate fields of 1 to 4 teslas.



Super strength. At 77 degrees kelvin, a new superconductor tape made of a material called YBCO *(blue)* carries more current than a rival *(purple)*, even in high magnetic fields.

In search of hardier materials, the Los Alamos researchers followed a trail blazed nearly 2 years ago by researchers at Fujikura Ltd. in Tokyo. The Japanese researchers, led by Yasuhiro Iijima, knew that a ceramic superconductor made of yttrium, barium, copper, and oxide (YBCO) was a much better performer at high magnetic fields. But it was harder to make into an HTS wire, in part because the usual HTS wire-making steps failed to align the YBCO grains.

So the Japanese team improved this alignment by laying YBCO crystals down on a preconfigured template. They started with a pliable nickel alloy as the base. On top of the alloy they laid down the template layer—another crystalline compound called yttria-stabilized zirconia (YSZ)—using a technique called ion beam–assisted deposition, or IBAD. This method grows YSZ crystals on the nickel alloy with only one particular orientation. And because YBCO's crystalline lattice has a similar structure, it naturally follows the YSZ orientation.

The technique allowed the researchers to achieve current densities of 500,000 A/cm^2. Yet there was room for improvement, because YBCO grains in the material were still 10 degrees out of alignment, on average. "That's where we came in," says Xin Di Wu, a member of the Los Alamos team.

By refining the alignment of the YSZ template, the researchers narrowed the YBCO misalignment to an average of between 5 and 6 degrees. Because "every degree improves your performance by 20 to 30%," Wu says, this increased the superconducted current to over 1 million A/cm^2 in the absence of a magnetic field, and a healthy 500,000 A/cm^2 when a magnetic field of 8 teslas was applied parallel to the surface of the tape.

Although the Los Alamos team remained close-mouthed about the details behind this feat, other researchers heard enough to raise some questions about the feasibility of the IBAD deposition process. "It's slow at the present time, which would make it more expensive to scale up," says Don Kroeger of Oak Ridge National Laboratory in Tennessee.

Kroeger and his colleagues think they have a faster way, eliminating the YSZ layer—and therefore the plodding IBAD process—and imparting the texture directly to the bottom metal substrate. Although just as circumspect on the details as their Los Alamos rivals, the researchers reported in San Francisco that running the substrate between what amounts to two rolling pins, among other unspecified steps, helps give it a texture that aligns subsequently deposited YBCO crystals within 10 degrees.

The Oak Ridge team has not shown, however, that their material superconducts at all, let alone in high magnetic fields. Nevertheless, Yurek calls the preliminary results "promising." If either the Oak Ridge or Los Alamos project bears out this promise, HTS magnets may turn out to be industrial superheroes after all.

–Robert F. Service