Putting SQUIDs to Work

Researchers are learning how to tailor the intransigent high-temperature superconductors into useful structures

WITHIN THE NEXT MONTH, scientists are likely to demonstrate one of the most promising applications of high-temperature superconductors: a SQUID magnetometer. In a friendly race, physicists from two different laboratories are close to achieving working models of the device, which could eventually be used for safe, nonintrusive examinations of the heart and brain, detailed studies of the earth's crust, and even detection of submarines hiding in ocean depths.

At the University of California, Berkeley, John Clarke expects to put the finishing touches on his magnetometer "in a few weeks, God willing." Close on his heels is a former student, Roger Koch, now at IBM's T. J. Watson Research Center in Yorktown Heights, New York. Both hope to have something to announce at the Applied Superconductivity Conference, 24 to 28 September, in Snowmass, Colorado.

SQUID magnetometers, which are sensitive detectors of magnetic fields, have already proven their worth in such uses as sensing weak magnetic signals from the brain for medical diagnoses. But to date, such devices have only been made with low-temperature superconductors, which must be cooled with expensive and difficult-to-work-with liquid helium. This has limited their commercial value.

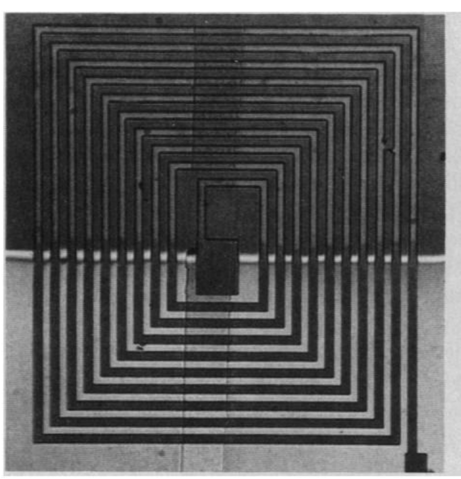
To overcome these limitations, researchers would like to make magnetometers from high-temperature superconductors, which lose their resistance to electric currents above 90 K. The high-temperature materials can be cooled with liquid nitrogen, which has a boiling point of 77 K, and nitrogen refrigeration systems are cheaper, simpler, and more portable than helium systems.

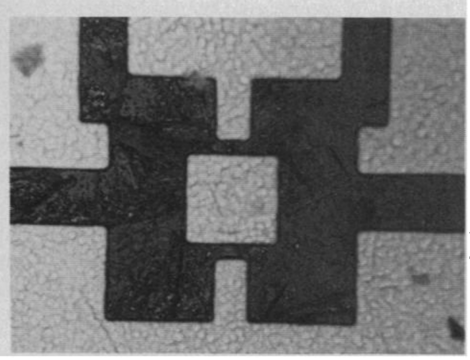
But in the 3 years since these high-temperature materials were discovered, few practical devices have been built from them. They are balky compounds that have proved difficult to form into the desired structures without damaging their superconductivity. The construction of a working magnetometer will show that high-temperature superconductors can indeed be used to make complicated instruments.

To do this, the teams faced two separate hurdles, and each attacked a different one first. At IBM, Koch's group took aim at the heart of the device: the SQUID, or superconducting quantum interference device.

A SQUID is basically a superconducting loop with two wire leads attached. Electrons can move around this circuit without resistance except at two points, where small breaks or barriers are built into the path. Here the electrons can get through only by tunneling—the quantum equivalent of digging a hole under a wall. Because of quantum mechanical interference effects, the voltage across the wire leads serves as a sensitive measure of the applied magnetic field.

The difficulty in making this seemingly simple device lies in the breaks—if they are more than a few angstroms across, the SQUID won't work. IBM's technique, says team member William Gallagher, is to make a thick circuit with two narrow necks. These necks will often have natural breaks in them because the superconductor consists of many individual crystals, or grains, and the boundary between two grains provides a barrier to electrical current. The researchers cannot guarantee the presence of such breaks, Gallagher notes, but about 5% of their attempted SQUIDs have the right combination of grain boundaries to produce a device that works at 77 K. Other labs have also made high-temperature SQUIDs, Gallagher notes, but most work rather poorly. IBM's have the best signal to noise of any of the devices so far reported, he says.





Ready for assembly. *A SQUID (below) combined with a flux transformer (only the input coil is shown) form a magnetometer.*

University of California, Berkeley/IBM

Meanwhile, Clarke's team at Berkeley decided to focus on the other half of the magnetometer: a "flux transformer" that amplifies magnetic fields in a way analogous to how old-fashioned ear horns magnified sound for the hard-of-hearing. To detect very weak magnetic fields, a device needs to have a large pickup area, but unfortunately, once SQUIDs get larger than about 40 micrometers square, Koch says, random noise begins to overwhelm the signal. The solution is to construct a "hearing aid" for the SQUID: a flux transformer with a large superconducting loop to detect magnetic fields, coupled to a small multiple-turn coil that generates an amplified version of the field, which is fed into the SQUID. The amplification is roughly proportional to the number of turns in the coil, so by increasing the number of turns it is possible to make a flux transformer that will amplify a magnetic field by hundreds of times.

At Berkeley, John Kingston, Fred Wellstood, and Clarke have succeeded in making flux transformers out of the high-temperature superconductor $YBa_2Cu_3O_7$ with input coils of up to 19 turns, which amplify the magnetic field almost ten times. The trick, Clarke says, was learning to make crossovers—two crisscrossing strips of superconductor separated by an insulating layer. The superconductor is so sensitive that it tends to lose its superconductivity when covered by a layer of another material, so it took the team nearly 6 months to build a crossover that worked at 77 K. In the past few months, they have formed a flux transformer with both a coil and an input loop. To show that the flux transformer works, they coupled it to a SQUID made from a low-temperature superconductor.

So the IBM and Berkeley groups have each built half of a magnetometer. "If you take one of our SQUIDs and put it on one of their pickup coils," Koch says, "it should work pretty well." But each team thinks it can build the other half by itself, so it will be a race rather than a collaboration.

Which team wins that race, Wellstood notes, will not be nearly as important as the technology developed along the way. In particular, the ability to make crossovers should open up many new electronic applications for high-temperature superconductors, of which the SQUID magnetometer is only the first.

■ ROBERT POOL