# Advance hastens practicality of superconductivity

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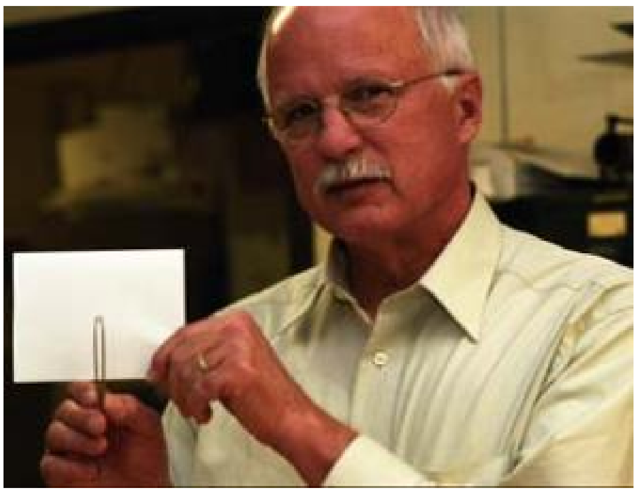

WUSTL Physicist James Schilling points out a tiny ceramic ring about the size of a small washer, key to a technique developed along with researchers at Argonne (Ill.) National Laboratory that could make superconductivity more practical.

Nobody completely understands superconductors. So fathom how James S. Schilling, Ph.D., led a team that makes the phenomenon work better. Schilling, a professor of physics in Arts & Sciences at Washington University in St. Louis, collaborated with recent doctoral graduate Takahiro Tomita and scientists at Argonne (Ill.) National Laboratory to determine whether one region in superconductors, called grain boundaries (GB), are oxygen deficient. Such oxygen deficiency impairs superconductor performance.

Their paper, titled "Enhancement of the Critical Current Density of $YBa_2Cu_3O_x$ Superconductors under Hydrostatic Pressure," is published in the Feb. 24 issue of the highly regarded journal *Physical Review Letters*.

A superconductor is a solid material that conducts electricity without resistance when it is cooled to certain subzero temperatures. Because there is no resistance, current uniquely travels through superconductors without losing energy.

Their study involves the newer, so-called "high-temperature" ceramic superconductors. They superconduct at less frigid temperatures than other superconductors, although still in the subzero realm.

The superconducting material used in this study was a ceramic compound consisting of millions of microscopic crystals (grains). The WUSTL/Argonne team specifically developed a technique to determine whether a desired maximum number of possible sites are filled with oxygen in the GB, which surrounds every crystalline grain. The GB is a region of misfit between the grains and usually is only a few atoms wide.

The study used the most widely employed ceramic superconductor, known as YBCO. YBCO (or $YBa_2Cu_3O_x$) simply represents its "yttrium-barium-copper-oxide" content.

## Fully oxygenated

Full oxygenation is essential for the manufacture of reliable ceramic superconductors. Maximizing oxygen in the GB helps maximize critical current density (Jc), or the maximum current that a superconductor can carry. In the subatomic world of superconductors, unrestricted current flow must be the outcome.

"Even in the best superconductors," Schilling noted, "GBs limit their ability to carry the high electric currents required for applications in electric power grids or to generate enormous magnetic fields. To enhance the current carrying capacity, it is essential to bathe the grain boundaries in as much oxygen as possible. Unfortunately, it is very difficult to determine how much oxygen is really present in the GB.

"We have developed a method which allows one to estimate this, called pressure-induced oxygen relaxation."

Boyd W. Veal, Ph.D., an Argonne physicist and a co-author of their paper, said the technique "could tremendously ease the superconductor manufacturing problem. There is hope that these discoveries can make (superconductor) materials more accessible for practical applications."

Until now, science had determined how to check ceramic superconductors' crystalline structures - but not their GBs - to ensure all potential oxygen sites were filled. It also was known that full oxygenation is essential. The investigators note in the paper, "Even when the bulk material is fully oxygenated, the GBs are likely oxygen deficient."

"This is the most applied thing we've ever done," Schilling said of his WUSTL research. "But we've done a huge amount of work in the past on oxygen ordering; that was in the (superconductor crystalline structure) bulk itself - not in the grain boundary."

## Current flowing without resistance

Electrical systems would run more efficiently if current flowed without resistance. Electrical voltage simply is current multiplied by resistance. At room temperature, all known materials resist electric current in varying amounts, including today's electrical wiring — which, therefore, loses energy.

"There's no way to explain superconductivity in simple terms. It's against intuition," Schilling said, finding no commonplace analogy for superconductors, which only can be explained using quantum mechanics. "It's like nothing you've ever experienced."

The phenomenon has been tweaked by scientists, including a few Nobel Prize winners, in an effort to achieve maximum current flow (Jc) at higher temperatures (as close as possible to room temperature) using various compounds. Generally, the lower the temperature and the higher the pressure, the better the current capacity (Jc). Magnetic field is another complicated variable in the mix. The goal of finding a superconductor that will function at room temperature is desired for many widespread practical applications.

For its superconductor, the WUSTL/Argonne study used a recently developed YBCO bicrystalline melt-textured ceramic ring — a small, brittle object that is about the size of a tiny washer. Chemical pressure up to 6,000 atmospheres (0.6 GPa) — or 6,000 times the air pressure of the earth's atmosphere — was applied by transmitting high-pressure helium gas into a compression chamber holding the ring. Then a magnetic field, which generates an electrical current in the ring, was applied.

In this study, the new "pressure-induced Jc relaxation" technique revealed whether there were vacant oxygen sites in the GB.

When there was a markedly and measurably strong change in the Jc with changes in pressure, it indicated that oxygen ordering (realignment) was occurring in the GB. Conversely, if all the GB oxygen sites already were filled when pressure was applied, there were only small changes in the superconductor's current - because the oxygen did not move. When the oxygen moved into vacant sites, "we knew because it affected the current capacity (Jc) in the grain boundary and the Jc went up," Schilling explained.

To preserve a superconductor with a fully oxygenated GB for manufacture, pressure would have to be released at "temperatures sufficiently low (less than 200 K or less than -73 C for YBCO) to prevent the oxygen (atoms) from diffusing back, thus effectively freezing in the higher degree of order," the investigators say in the paper.

Schilling said researching the oxygenation of GBs under pressure was built on Veal's earlier work. "This turned out to be a very challenging thing - not an easy solution," said Veal, who is one of the world's most cited physicists in the physical sciences. "Solving this GB problem could have huge commercial impact."

## Room temperature is the ideal

Like analyzing plant life for pharmaceutical answers to disease, one broader quest for physicists is to discover the most practical combination of elements that will superconduct current — ideally closer to or at room temperature. Since the phenomenon first was encountered in 1911 by a physicist applying an electric current to mercury at nearly absolute zero (4.2 K or -269 degrees C), the basic process has undergone innumerable substitutions. As in perpetual motion, current will flow forever in a closed loop of superconducting material.

In one atmosphere of pressure, the YBCO superconducts at 93 K (or -180 C) — which is well above the temperature required of earlier superconductors. Sometimes, this critical transition temperature (Tc), or the temperature below which a material begins to superconduct, can be pushed higher with the application of higher pressure. YBCOs can superconduct at temperatures as high as 110 K (-163 C) at highest pressure (about 100,000 atmospheres). But, to date, no superconductor Tc has remotely neared room temperature.

Schilling, who joined the WUSTL faculty as a professor in 1990, earlier conducted research for 21 years in Germany. He was a professor of applied physics at the University of Munich and primarily worked in high-pressure physics research. The Little Rock native is a Fellow of the American Physical Society and is the only faculty physicist at WUSTL studying superconductors.

"In Munich, we discovered the effect that oxygen rearranges under pressure in the superconductor bulk and causes a big change in the Tc. Then, we were studying the crystal (structure itself) instead of the GB," Schilling said.

Source: Washington University in St. Louis

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