Pushing the Boundaries of High-Temperature Superconductors

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A collaboration led by scientists at the U.S. Department of Energy's Brookhaven National Laboratory has revealed a new mechanism that explains why adding calcium to a high-temperature superconductor increases its current-carrying capacity. The findings refute the current explanation and open the door for similar additives with potentially better current-boosting abilities. The study is published in the May 26, 2005, edition of *Nature*.

In theory, high-temperature superconductors conduct electricity with no resistance. But the most practical, inexpensive high-temperature superconducting materials — those suitable for applications such as electronic devices and power lines — are made of many tiny crystalline grains. The boundaries between grains act like barriers to electric charge carriers, impeding the flow of current.

This is the case for the superconducting material studied here, known as YBCO for its constituent elements: yttrium, barium, copper, and oxygen. Scientists had previously discovered that adding calcium to the boundary between two grains in YBCO improves the current flow, seemingly because the calcium changed the electric-charge structure at the boundaries. Surprisingly, this latest study shows that the position of the calcium atoms at the boundary is different than previously assumed — that is, it is the chemical structure of YBCO after adding calcium that leads to improved conductivity.

"At YBCO grain boundaries, calcium atoms replace some of the barium and copper atoms," said Brookhaven physicist Robert Klie, the paper's lead author. "Where the atoms are tightly packed, a calcium atom replaces a larger barium atom, relieving the strain. Oppositely, in loosely packed areas, the calcium replaces a smaller copper atom, which relaxes strained areas that are nearby."

The substitutions regulate the atomic structure at the boundaries, providing additional "pathways" for electric charge carriers to pass from grain to grain. "This finding is surprising because we thought only calcium could improve the grain-boundary conductivity of YBCO, but our discovery means that similarly sized elements could be equally or more effective," said Klie.

Klie and Brookhaven scientist Yimei Zhu, one of the paper's co-authors, made the discovery using the scanning transmission electron microscope at Oak Ridge National Laboratory. The microscope is a powerful imaging device that uses a beam of high-energy electrons to examine objects at a very small scale. The resulting images of YBCO are the first to reveal the composition of the boundaries at the atomic level, allowing the researchers to identify, atom-by-atom, the chemical make-up of the material after the addition of calcium.

As part of this ongoing collaborative research, the YBCO sample was fabricated at the University of Göttingen in Germany and its electronic properties were previously measured at Brookhaven by Zhu's group. The collaboration also includes researchers from Vanderbilt University, the University of California at Davis, and The University of Tokyo.

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Source: Brookhaven National Laboratory