Materials with superpowers

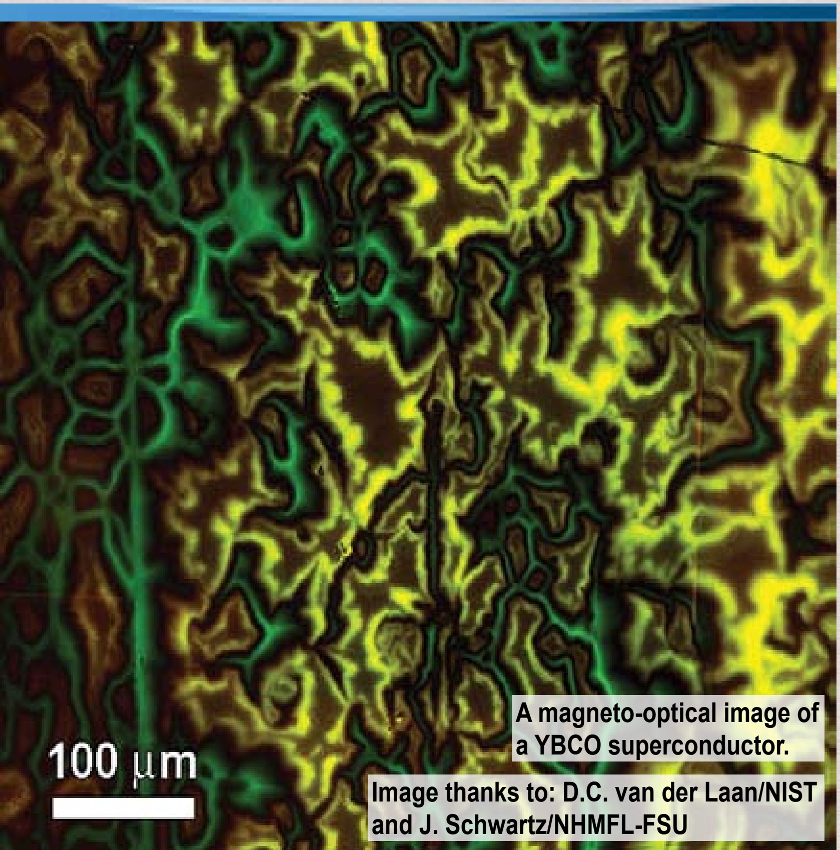
High-temperature superconductivity combines mystery and possibility

By Susan Ray

Although superconductivity was discovered in 1911, in many ways the history of superconductors is only just beginning, and research at the National High Magnetic Field Laboratory is shaping that history.

The man who discovered superconductivity – Dutch physicist Heike Kammerlingh Onnes – showed that certain materials (in his case, mercury) conduct electricity with no resistance when cooled to 4.2 Kelvin. That's about -451.84 degrees Fahrenheit!

Electricity comes from electrons traveling through wire conductors. Those electrons bumping into each other generate friction, which in turn generates an enormous amount of heat. With superconductors, however, there is no friction – that's what "no resistance" means.



A magneto-optical image of a YBCO superconductor.

Image thanks to: D.C. van der Laan/NIST and J. Schwartz/NHMFL-FSU

It wasn't until 1956 – 45 years later – that scientists developed a solid theory of why superconductors behave as they do. That theory, called the BCS Theory after its creators, John Bardeen, Leon Cooper and Robert Schrieffer, as well as Onnes' discovery years earlier, were Nobel-honored landmarks in the world of physics.

Since the earliest days of the discovery of superconductivity, scientists have been working to raise the temperature at which materials become superconducting, recognizing the potential commercial applications of superconductors. The cost of the liquid helium required to cool the materials to extremely low temperatures, as well as difficulty fabricating the superconductors into a usable form, limited the usefulness of superconductors.

By the mid-1980s things were heating up … literally. In 1986, IBM researchers Karl Muller and Johannes Bednorz discovered a material that becomes superconducting at 36 Kelvin, or -394.6 degrees Fahrenheit. That discovery, which also netted a Nobel Prize, kicked off a frenzy of research into similar materials that continues to this day.

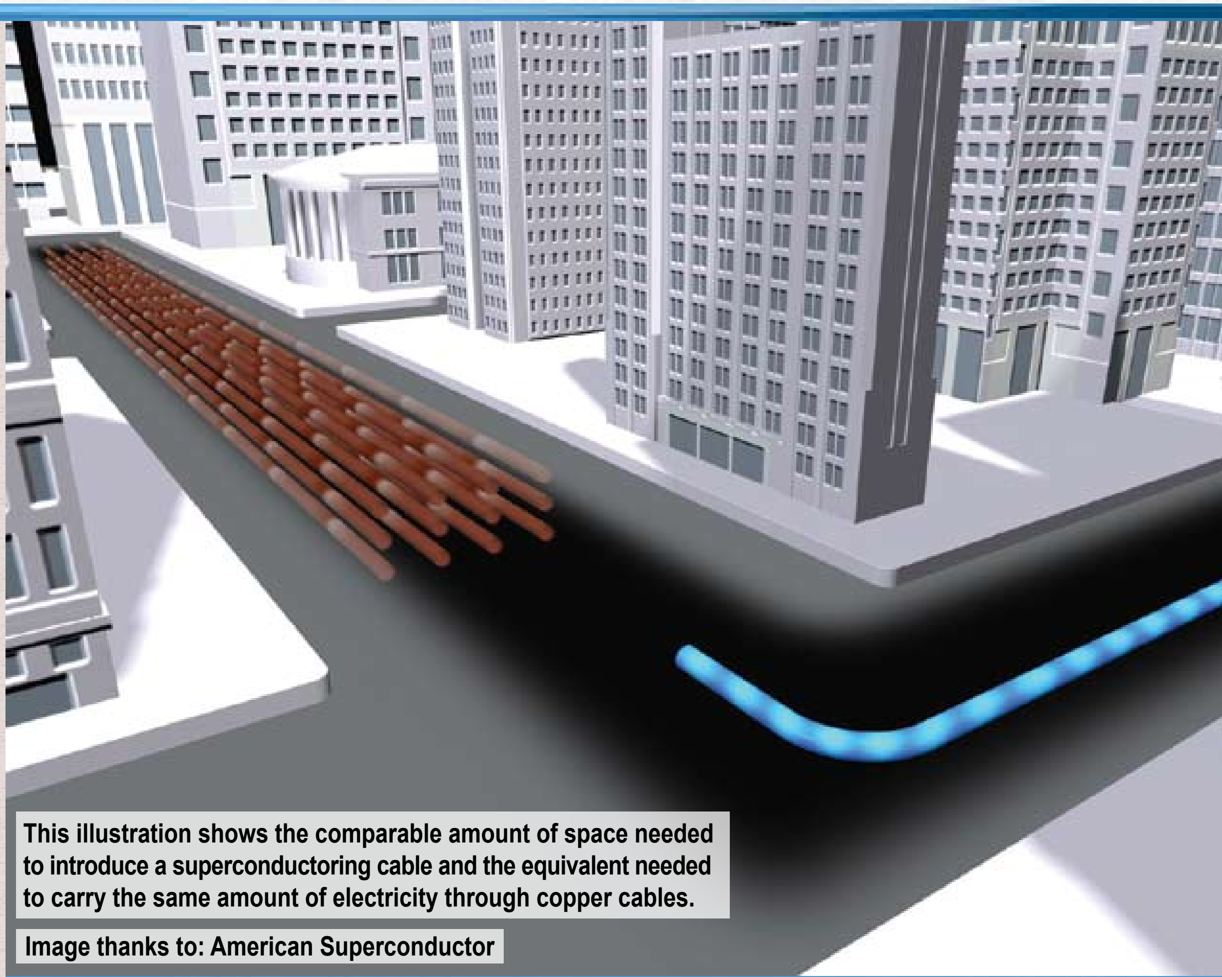
A compound called yttrium barium copper oxide – or YBCO – was found in 1987 to achieve superconductivity above the boiling point of liquid nitrogen – a still frigid -320.5 degrees Fahrenheit. Materials that become superconducting above that point are called high-temperature superconductors (HTS), and they are so significant because they can be cooled with liquid nitrogen, which is relatively inexpensive and easily handled.

"The discovery of high-temperature superconductors made the idea of using superconducting materials for power transmission feasible," said Magnet Lab Director Greg Boebinger, whose research interests include high-temperature superconductors.

Materials research done at the Magnet Lab and its world famous Applied Superconductivity Center promises to lead to new discoveries in this field, and collaborations with industry help pave the way for emerging technologies.

Mag Lab scientists and engineers have worked with companies such as American Superconductor, an energy technologies firm based in Massachusetts that is developing superconducting cables for utility applications.

"Basic research is very important to American Superconductor, particularly in developing our HTS wire processes," said Alexis Malozemoff, Ph.D., the company's executive vice president and chief technical officer. "We have worked closely in this area with U.S. national labs and universities that have made important contributions."



This illustration shows the comparable amount of space needed to introduce a superconductoring cable and the equivalent needed to carry the same amount of electricity through copper cables.

Image thanks to: American Superconductor

Industry is moving ahead with applications of high-temperature superconductors, but scientists still don't have a solid theoretical understanding of high-temperature superconductivity; it remains one of the most important unsolved riddles in physics. And scientists worldwide are still seeking the Holy Grail of physics: room-temperature superconductors, which would eliminate the need for liquid nitrogen, making superconducting materials more inexpensive and practical.

Back at the Mag Lab…

So what do high magnetic fields have to do with the study of superconductors? Plenty. Electricity and magnetism are forever intertwined. Magnetic fields can be used to probe the nature of these materials. At lower fields, superconductors repel magnetic fields (this is called the Meissner effect, a phenomenon often demonstrated at science fairs by a small magnet floating magically above a superconducting material). But in their research, scientists found that higher magnetic fields start to penetrate the superconductor, and it eventually loses its superconductivity. This presents all kinds of interesting scenarios for scientists to study.

"Because scientists know high magnetic fields kill superconductivity, they can study promising materials in high magnetic fields to learn how to make the materials more robust," said Boebinger. "If the materials can resist high magnetic fields, they also can resist destructive high temperatures. The superconductors of the future must be able to operate at high temperatures at high fields while carrying high currents."

According to Boebinger, 56 percent of the energy generated by power plants can't be utilized. About half of that is off limits for fundamental science reasons, he said. The rest can be conserved or used – but only if we have new technologies.

"Superconductors could be the biggest breakthrough in this area," said Boebinger. "Superconductors conduct electricity without friction. That's important because friction on standard conductors is what generates heat, and energy is lost in the process."

The technology is already moving in that direction. Currently, two superconducting power line projects are underway in New York, the Albany High-Temperature Superconducting Cable Project and Project Hydra (see sidebar), and superconductors could have great impact elsewhere.

"We see superconducting cables based on HTS wires having broad impact in addressing capacity constraints in dense urban areas, and longer term, providing a backbone of the electric power grid around the country," said Malozemoff. "HTS wires also underlie many other applications opportunities – motors, generators, transformers, fault current limiters, etc. Other markets closer to the consumer could include coils for Maglev trains and MRI systems."

Outside of consumer applications, high-temperature superconductors can be used to make high-field magnets that are less costly to operate. The Magnet Lab regularly tests HTS materials to for its next-generation magnets.

SEE HOW IT WORKS

Watch animations depicting how secure super grid systems can protect electrical grids at: http://www.amsc.com/products/hydra.cfm

Liquid nitrogen, the coolant required to maintain superconductor cables at their operating temperature, flows through a cable that can transmit many times more power than copper cables of the same diameter.

Image thanks to: American Superconductor

SUPERCONDUCTIVITY IN ACTION

Superconductor technology has attracted great interest from utility companies and the Federal government. According to industry advocates, electric power transmission cables crafted from high-temperature superconductor material can carry between seven and 10 times more current than conventional cables. This reduces power grid congestion as well as installation and operating costs, all with a low environmental impact. Several projects are underway; two are profiled here:

Albany High-Temperature Superconducting Cable Project: On July 20, 2006, the world's first in-grid superconducting power cable, developed by SuperPower Inc., was energized in Albany, N.Y. In the project's second phase, completed in February of this year, a superconducting power cable made of a more cost-efficient and high-performance second-generation wire replaced 30 meters (90 feet) of the cable. The 350-meter (1148-feet) HTS cable runs between the Riverside and Menands substations. The $27 million dollar project is funded by the U.S. Department of Energy and the New York State Energy Research and Development Authority.

Project HYDRA: This project focuses on the development and deployment of superconducting technology developed by American Superconductor in the Con Edison-operated power delivery network in lower Manhattan. The "Secure Super Grids" technology utilizes HTS power cables and ancillary controls to deliver power through the grid while at the same time suppressing power surges – or fault currents – that can disrupt service. A 50-meter (164-feet) prototype cable is expected to be in place by year's end, and the full-scale, 300-meter (984-feet) power cable system is scheduled to be operational in 2010. The Department of Homeland Security is providing $25 million for the $39 million project.