Superconductor Week

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IEE-CAS Creates a Prototype Hybrid Superconductor/Natural Gas Line

Researchers at the Institute of Electrical Engineering of the Chinese Academy of Sciences (IEE-CAS) have developed a prototype of a hybrid superconducting power transmission line that carries both electricity and natural gas. The 10-meter line is intended to demonstrate the feasibility of the technology, which could eventually be used in the construction of a long-distance line from the resource-rich west to the eastern provinces of China.

"Originally this was my idea, which was then supported by the Frontier Research of CAS in 2016," commented Professor Liye Xiao, the Director of the Applied Superconductivity Laboratory of IEE-CAS. "In 2017, I proposed that this idea be supported by the Smart Power Grid Project (SPG) which is a broader program supported by Ministry of Science and Technology of China. This support was given in 2018."

BSCCO Cable Transmits 800 Amps of Current at More Than 10,000 Volts

The prototype consists of a DC superconducting cable that is located in the core of the power line, with the capability of transmitting about 800 amps of electric current at more than 10,000 volts cooled to 100 K. Natural gas flows in the gap between the superconductor and the line's outer shell.

The natural gas is liquefied to temperatures of 90 - 100 K so that it also functions as a coolant for the superconducting cable. With the completion of testing, the IEE-CAS team is preparing a paper on the results to be submitted to a scientific journal.

"Actually, the superconducting cable core is an old one, made in 2002-03 using BSCCO wire from AMSC," Xiao said. "For this project, we changed the construction of the cable's cooling system and its terminator so that it could be used to transport the LNG safely."

Longer Prototype to Include Two Superconducting Cable Cores

The prototype line has enabled the IEE-CAS scientists to deal with a number of technical problems, such as reducing the risk of accidents from electrical sparks and gas leakage. They have insulated the thermal conduction between the cable core and the LNG and have instituted at the terminator separate outlets for electricity and LNG.

The team is currently working on another prototype line that will be 30 meters long. The voltage will be greater or equal to 100kV, and

Team Developed Analytical Model for Evaluating Stresses in HTS Films

The research team developed an analytical model for evaluating the electromagnetic-force-induced stresses in a thin HTS film that is placed in a vertical magnetic field. The model relates curvatures to film stresses through electromagnetic body force, whose mechanism is different from common film stress sources like misfit strain or thermo mismatch. The new model shows that the film stresses depend not only on the local curvatures at a same point of the substrate but also on the nonlocal curvatures of other points.

"The model in this work represents a first attempt at measuring electromagnetic stress in HTS films," said Zhang. "Models that also provide a way to reduce these stresses or to make the films more stress resistant are still under development and not functional."

Team Implements Coherent Gradient Sensor System

The research team implemented a coherent gradient sensor system for cryogenic measurement to monitor the stress states of the HTS film during the processes of magnetization and demagnetization. They measured the full fields of hoop stress, radial stress of the $YBa_2Cu_3O_{7-x}$ film, and shear stress at interface between the film and the $SrTiO_3$ substrate subjected to various magnetic fields. They found that all the stresses manifest irreversible behavior, which is first experimentally found in the thin HTS film-substrate system.

"Studies detailing the use of the coherent gradient sensor at cryogenic temperatures have been published previously," Zhang said. "These include studies on the modification of curvature measurements, experimental validation, and cryogenic vacuum chamber design.

"The irreversible stress behavior is closely related to its irreversible magnetization property, which means HTS films with strong flux pinning exhibit a non-linear magnetic field dependent behavior. Their film stress is closely relevant to the history of the applied magnetic fields.

"The stress maps made during this study reveal that high stresses are often found near the periphery of the film which indicates that in practical applications, this area needs to be carefully developed. The next step in our research is to study film stress under high magnetic fields, up to several Tesla, and we also want to study how to make films more stress-resistant." ❍

CAS Synthesizes New Cuprate Superconductor with Novel Characteristics

A research team led by the Institute of Physics of the Chinese Academy of Sciences (CAS) has observed high T_c superconductivity in the cuprate Ba_2CuO_{4-y} (Ba214) with unique features that include an exceptionally compressed local octahedron and heavily overdoped hole carriers (doi.org/ 10.1073/pnas.1900908116). These characteristics are in sharp contrast to those for all previously known cuprate superconductors and call into question the widely accepted scenario of superconductivity in cuprates.

The discovery suggests a new direction for searching for additional high-T_c superconductors. Also participating in the research were scientists from the U.S. National Institute of Standards and Technology (NIST) Center for Neutron Research, Columbia University, the Max Planck Institute for Chemical Physics of Solids, Taiwan's National Synchrotron Radiation Research Center, the Nanjing University of Science and Technology, and the University of Florida.

Study Expands Lattice Parameters of CuO_2 Plane

The mechanism of superconductivity in cuprates remains one of the great challenges of condensed matter physics. High-T_c cuprates crystallize into a layered perovskite structure featuring copper oxygen octahedral coordination. Due to the Jahn Teller effect in combination with the strong static Coulomb interaction, the octahedra in high-T_c cuprates are elongated along the c axis, leading to a $3dx^2$-y^2 orbital at the top of the band structure where the doped holes reside. This structure gives rise to the single band characteristics in high-T_c cuprates that favor d-wave pairing symmetry.

"This study is related to fundamental research on searching for new superconductors," said Professor Changqing Jin of the CAS Institute of Physics. "The motivation is to expand the lattice parameters in the CuO_2 plane as large as possible in order to reduce the elongation distortion or, to some extent, toward a compressed octahedron version in order to introduce a multiband scenario, since Ba^{2+} seems to be the largest ion that can be incorporated in to the 214 structure."

T_c of New Material 30 K Higher than Conventional Ba214

The CAS team synthesized Ba214 at high oxygen pressures of 18 GPa and a high temperature of 1000 C using a 6~8 double stage type large volume facility. Since the radius of the Ba^{2+} ion is too large to be incorporated in the 214 structure under ordinary conditions within the designed framework, high oxygen pressure was necessary to synthesize the bulk materials with a metastable structure.

The researchers observed a compressed local octahedron resulting in a reversed orbital order with $3z^2$ lifted above $3dx^2$-y^2 leading to a strong multiband scenario. Furthermore, the overdoped state exceeded what had previously been achieved for a superconducting phase. The new material demonstrated a T_c above 73 K, 30 K higher than that of the isostructural classical ìconventionalì superconductor with elongated octahedron based on La_2CuO_4.

"The parent compound of the first-discovered cuprate superconductor $(La\ Ba)_2CuO_4$ has the K_2NiF_4 (214) type layered perovskite structure featuring Cu -O octahedral coordination which forms[CuO_2]planes," Jin said. "Since the oxygen octahedron in real cuprates is elongated along the c axis due to the Jahn Teller effect of the Cu^{2+} ion as well as the strong interlayer static Coulomb interaction, the two e_g orbital levels are split into a higher $3dx^2$-y^2 and a lower $3dz^2$-r^2 (simplified as $3dz^2$) orbital level.

"Carriers that are responsible for superconductivity are located primarily at the $Cu3dx^2$-y^2 orbital while the $3dz^2$ is located well below the Fermi level and is believed to presumably play a minor role in high T_c superconductivity. This single band scenario forms a basis for the majority theory of high T_c cuprates. Hence the lift of $3dz^2$ orbital in Ba214 provides the hitherto multiband scenario in cuprates superconductors showing dramatic enhancement to Tc."

Extra Oxygen Stabilized the Lattice

The necessary high doping level was determined by the amount of oxygen in the new structure, as obtained through high pressure synthesis. Extra oxygen had to be introduced into the lattice to stabilize the structure.

Jin commented how further research would proceed: "Our first step is to stabilize Ba214 since it is the simplest structure to accommodate compressed local octahedron in cuprates. We will further work on single crystal growth if possibly to study in depth the new physics of the superconductor; certainly we will proceed to other cuprates with the same scenario aiming to further increase T_c or to find new effects."

The research received financial support from the National Science Foundation, as well as Ministry of Science & Technology of China through research projects. ❍