Superconductivity Physicists Puzzled by the Weird Behavior of Electrons

July 30 2004

The weird behavior of electrons tunneling across an atomically flat interface within a cuprate superconductor has defied explanation by theories of high-temperature superconductivity.

As will be reported in the journal Physical Review Letters, a team of scientists led by physics professor James Eckstein at the University of Illinois at Urbana-Champaign has found **a large particle-hole asymmetry in the density of states of excitations in high-temperature superconducting tunnel junctions embedded in a single crystal heterostructure**. Since superconductors are supposed to possess particle-hole symmetry – according to current theories – **new theoretical work may be required to explain the strange results**.

In tunneling spectroscopy of superconductors, the differential conductance is proportional to the density of states in the superconductor. “Below the superconducting transition, the tunneling conductance showed a large unexpected asymmetrical feature near zero bias,” Eckstein said. “This is evidence that crystals of high-temperature superconductors, atomically truncated with a titanate layer, have intrinsically broken particle-hole symmetry.”

At negative bias (corresponding to tunneling of electrons from states with particle-like character) the spectra exhibited the expected superconducting gap. However, at positive bias (corresponding to tunneling of electrons into states with hole-like character) the spectra showed a dramatic step-like increase. “This clearly demonstrates the breaking of symmetry between particle-like and hole-like excitations at this interface in the superconducting state," Eckstein said.

The junction heterostructures were very carefully grown by oxide molecular beam epitaxy and optimized using in situ monitoring techniques, resulting in unprecedented crystalline perfection of the superconductor/insulator interface. It was the precise truncation of the crystal lattice at the calcium titanate interface that led to the new results.

"The interface density of states was strongly modified by superconductivity, as expected, but the resulting excitation spectrum was not particle-hole symmetric," Eckstein said. "This indicates that at the surface into which the tunneling occurred, superconductivity is very different from what it is like away from the interface."

While the origin of this effect is still being debated, it depends critically on the high degree of crystalline perfection obtained at the insulator-superconductor interface.

"The presence of this well-defined interface obviously perturbs the superconductivity," Eckstein said. "So these results can provide a new test for theories of high-temperature superconductivity."

The co-authors of the Physical Review Letters article are Eckstein, Bruce Davidson at the INFM-TASC National Laboratory in Italy, Revaz Ramazashvili at Argonne National Laboratory in Illinois, and Simon Kos at Los Alamos National Laboratory in New Mexico. The U.S. Department of Energy, National Science Foundation and Office of Naval Research funded the work.

Source: University of Illinois at Urbana-Champaign