Microscopic Mechanism in High T_c Superconductors

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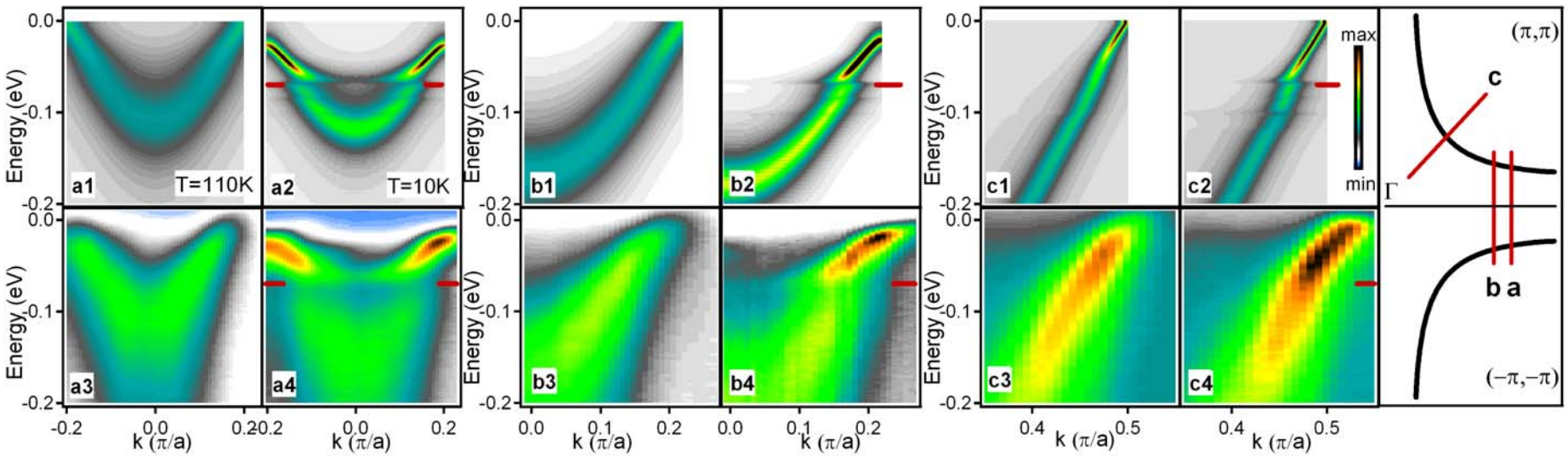

The microscopic mechanism underlying the conventional superconductors is the interaction between the electrons and the motions of the atoms (phonons) in the material. So far, no consensus on the mechanism has been reached for the copper-oxide superconductors, with considerably higher transition temperatures (T_c). One of the prominent experimental signatures of electron-phonon "coupling" is an abrupt change in velocity of the electronic bands at the phonon energy. In the figure (bottom row), we show this signature in Angle-Resolved-Photoemission-Spectroscopy data mapping out the dispersion of the electronic bands in a classic High T_c superconductor ($Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_8$, T_c = 94K) where the velocity changes abruptly at ~70meV in the superconducting state. In the figure (top row), we show a calculation of the bare electronic spectral function coupled to a phonon of B_{1g} symmetry and energy of 35meV. We find good agreement between experiment and the phenomenological theory due in particular to the anisotropy of the band-structure, the symmetry of the phonon, and a collusion of energy scales. This experiment indicates that the B_{1g} phonon plays an important role for this superconductor.

Superconductors are materials that can conduct electricity without any resistance and are potentially important for a wide range of applications. However, superconductivity usually occurs at extremely low temperatures, often just a few degree above the absolute zero (or -273 degree C). Therefore, the application of superconducting materials is not convenient and is expensive. The discovery of high temperature superconductors, with the transition temperature almost an order of magnitude higher than that of the conventional superconductors, has generated considerable excitement for both scientific and technological reasons. For one thing, the higher transition temperature makes the cooling less demanding and thus less expensive for applications. Understanding the underlying physics that gives rise to the unexpectedly high transition temperature will provide insight to further improve the materials, and possibly to further optimize the transition temperature. In the conventional superconductors, the microscopic mechanism is the interaction between the electrons and the motions of the atoms (phonons) in the material. For the high temperature superconductors, the evidence of electron-phonon interaction remains elusive, thus raising the question whether the electron-phonon interaction is relevant to this class of material. Our experiment using high resolution angle-resolved photoemission spectroscopy reveals evidence of strong electron-phonon interaction. More importantly, the interaction of electrons to a particular oxygen related phonon is strong and highly angular dependent. This angular dependence correlates well with the angular dependence of the strength of superconductivity (as measured by the pairing strength of two partner electrons to form the basic unit of superconductivity). This angular dependence is highly unusual for conventional superconductors, and is potentially very important to understand the high temperature superconductivity. Our two papers (experiment and theory) will be published in the same issue of Physical Review Letters.

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Education:

One graduate student (T. Cuk), three post-docs (F. Baumberger, N. Ingle, X.J. Zhou), one research scientist (D.H. Lu), and three professors (Z.X. Shen, T. Devereaux, N. Nagaosa) contributed to this work. Samples were provided by Hiroshi Eisaki and Nobu Kaneko. T. Cuk is now in her fifth year of graduate studies at Stanford University. F. Baumberger and D.H. Lu are continuing in the group of Z.X. Shen. N. Ingle and X.J. Zhou will continue their spectroscopy research in Canada and China respectively.

Societal Impact:

Understanding the nature of the superconductivity in high T_c materials could lead to better control and tuning between the known insulating and superconducting phases of copper-oxides. It could also lead to the manufacture of materials with higher T_c. Both would be technologically important for a wide range of applications. The education of graduate student and postdoc is important to the future workforce of the society.