ARPES Investigation of Pseudogap in Bi2212

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Cuprate superconductors are characterized by high critical temperatures exceeding liquid nitrogen temperature (77K), giving them a strong potential for industrial applications. However, a dip in the density of electronic states near the Fermi energy, named the pseudogap, was found to reduce the number of electrons contributing to the superconducting state, and, as a result, decrease the critical temperature. A better understanding of the pseudogap and superconducting states may allow the critical temperature of these superconductors to be further increased. The current study employed Angle-Resolved Photoemission Spectroscopy (ARPES) to characterize the superconducting gap and pseudogap of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212), a high critical temperature cuprate superconductor. A high-quality single crystal sample of optimally doped Bi2212 (Pb = 0.4, Y = 0.05) was prepared by the Traveling Solvent Floating Zone (TSFZ) technique. Its orientation and crystallinity were confirmed via X-Ray Diffraction (XRD). The sample’s electron transport and thermodynamic properties (electrical resistivity, magnetic susceptibility, and Seebeck coefficient) were measured over a wide temperature range from 5 to 300 K. Finally, ARPES measurements were performed to investigate the energy-momentum dispersion of conduction electrons in close vicinity to the Fermi energy. These measurements allowed us to study the evolution of the pseudogap and superconducting gap as a function of temperature and Fermi vector on the 2D Fermi surface. Ultimately, it is hoped that this work will lead to a better understanding of cuprate superconductivity in the optimally doped regime.
Investigation of Pseudogap in High-$T_c$ Cuprate Superconductors – Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

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Background and Purpose

Superconductivity:

- Normal Metal
- Superconductor
- Phonons
- Neutral defects
- Resistivity
- Transition temperature ($T_c$)

Pseudogap:

- Results in apparent gap ($\Delta$) in electronic density of states
- Energy gap in electronic density of states found in cuprate superconductors above $T_c$ (origin unknown)
- Competes with superconducting gap (decreases critical temperature)
- Suppress pseudogap $\Rightarrow$ increase $T_c$

Material—Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (Bi2212):

- High $T_c$ Superconductor (~93K)
- Doped with Pb and Y to control hole concentration (affects pseudogap)
- This sample: (Bi$_{1-x}$Pb$_x$)$_2$(Ca$_{0.65}$Y$_{0.35}$)Cu$_2$O$_{8+\delta}$ (optimally doped)

Purpose:

Characterize pseudogap and superconducting gap of Bi2212 sample in optimally-doped regime in order to gain a better understanding of superconductivity in cuprates, with the hope of ultimately raising the $T_c$ of these materials further.

Experimental Procedure

1. Dry, mix, and decarbonate (700 °C, 24 hours) raw materials (Bi$_2$O$_3$, PbO, SrCO$_3$, CaCO$_3$, CuO).
2. Grind and heat for solid state reaction (72 hours).
3. Take XRD and check the present phases.
4. If purity is not high enough, repeat 2 and 3 at a higher temperature.
5. Grow single crystal in Traveling Solvent Floating Zone Furnace (TSFZF).
6. Analyze sample with XRD, PPMS, and ARPES.

Results and Discussion

Powder XRD

- Recovered Bi2212 phase after 865 °C heating.

Rietveld Analysis of Single Crystal XRD

- Single crystal shows high crystallinity and pure Bi2212 phase.

Magnetic Susceptibility

- Peak maximum $\Rightarrow$ presence of pseudogap.

Resistivity

- Optimal doping
- High critical temperature (~97 K)

Seebeck Coefficient

- High temperature (~101 K) $\Rightarrow$ presence of pseudogap.

Future Work

- Look for dispersion pattern in current sample or samples with the same doping condition.
- Study samples with different doping conditions.
- Use ARPES to learn about the relationship between hole concentration and pseudogap characteristics.
- Vary parameters to possibly suppress pseudogap.

Acknowledgements

- 2017 Nakatani Foundation (http://nakatani-ries.rice.edu/)
- Professor Takeuchi, Dr. Sobota, and the rest of the Toyota Technological Institute Energy Materials Lab