ARPES Investigation of Pseudogap in Bi2212

W. Funkenbusch[1,2], R. Sobota[3], and T. Takeuchi[3]

[1]*Chemical Engineering Department, University of Rochester, Rochester, NY, USA*
[2]*Nakatani Research and International Experience for Students Fellowship in Japan, Rice University, Houston, TX, USA*
[3]*Energy Materials Laboratory, Toyota Technological Institute, Toyota, Japan*

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 $Bi_2Sr_2CaCu_2O_{8+\delta}$ (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 – $Bi_2Sr_2CaCu_2O_{8+\delta}$

William Funkenbusch,[1,2] R. Sobota,[3] and T. Takeuchi[3]
[1]Chemical Engineering Department, University of Rochester, Rochester, NY, USA
[2]Nakatani Fellowship Program, Rice University, Houston, TX, USA
[3]Energy Materials Laboratory, Toyota Technological Institute, Toyota, Japan
Contact Information: wfunkenb@u.rochester.edu

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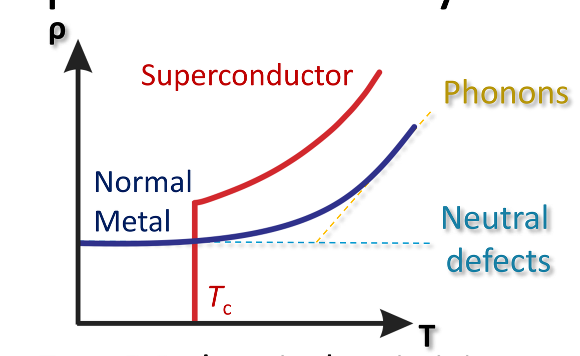
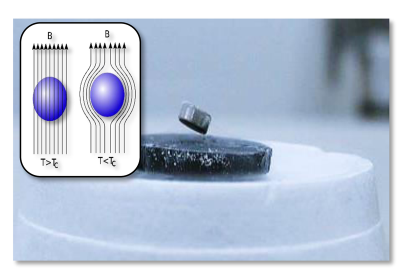
Background and Purpose

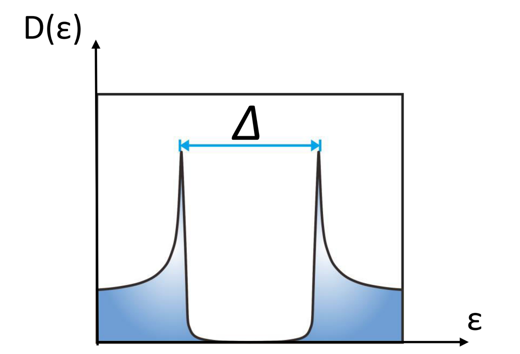
Superconductivity:



Zero DC electrical resistivity below critical temperature (T_c)

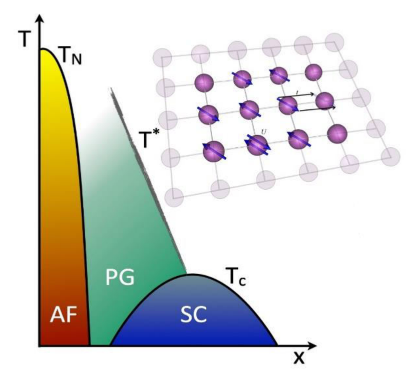


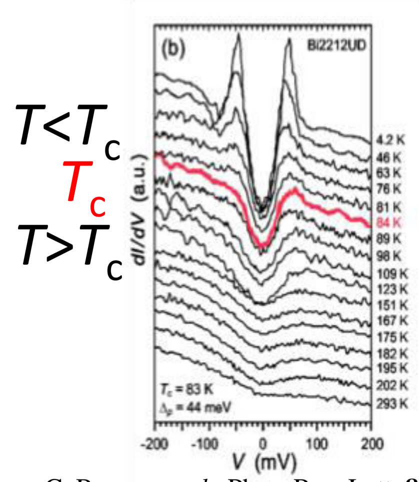
Meissner Effect: expels magnetic fields below T_c



Results in apparent gap (**Δ**) in electronic density of states

Pseudogap:

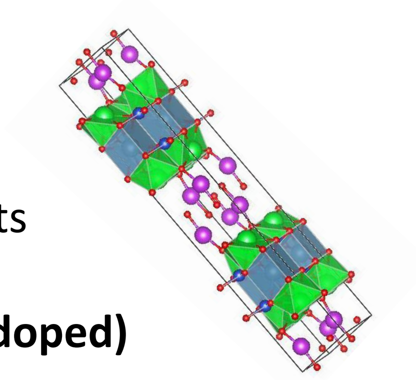




C. Renner *et al.*, Phys. Rev. Lett. **80**, 149 (1998).

- 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 -> increase T_c?

Material—$Bi_2Sr_2Ca_1Cu_2O_{8+\delta}$ (Bi2212):



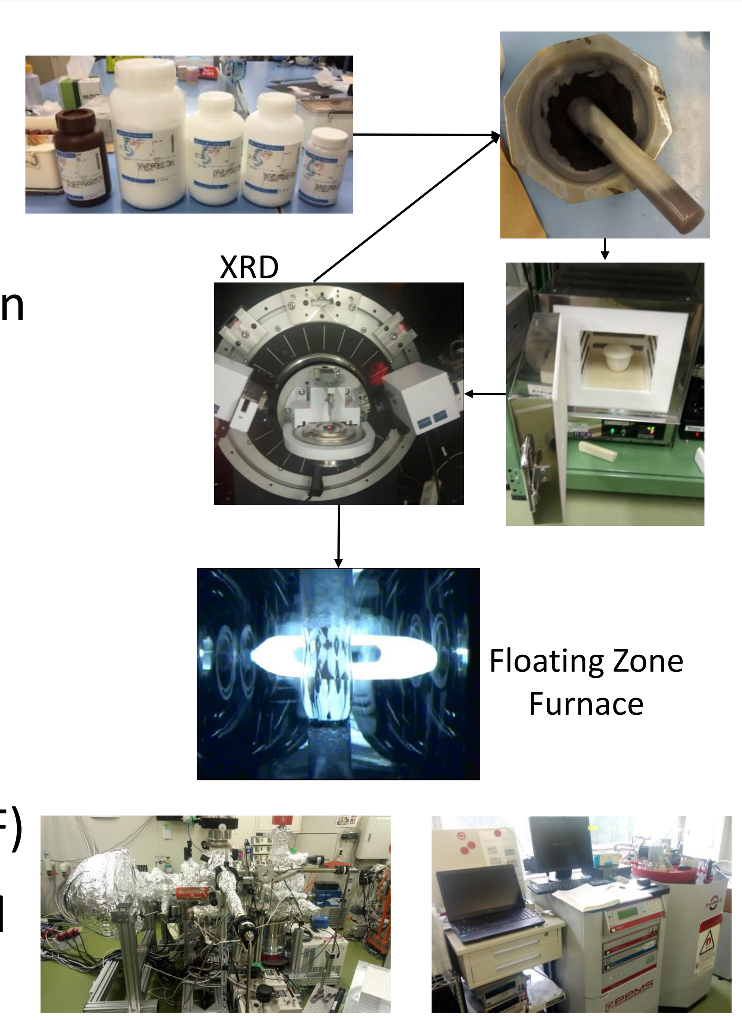
- **High T_c** Superconductor **(~93K)**
- Doped with Pb and Y to control hole concentration (affects pseudogap)
  - This sample: **$(Bi_{1.7}Pb_{0.4})(Ca_{0.95}Y_{0.05})Cu_2O_{8+\delta}$ (optimally doped)**

Purpose:

Characterize pseudogap and superconducting gap of Bi2212 sample in optimally-doped (max-T_c) 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

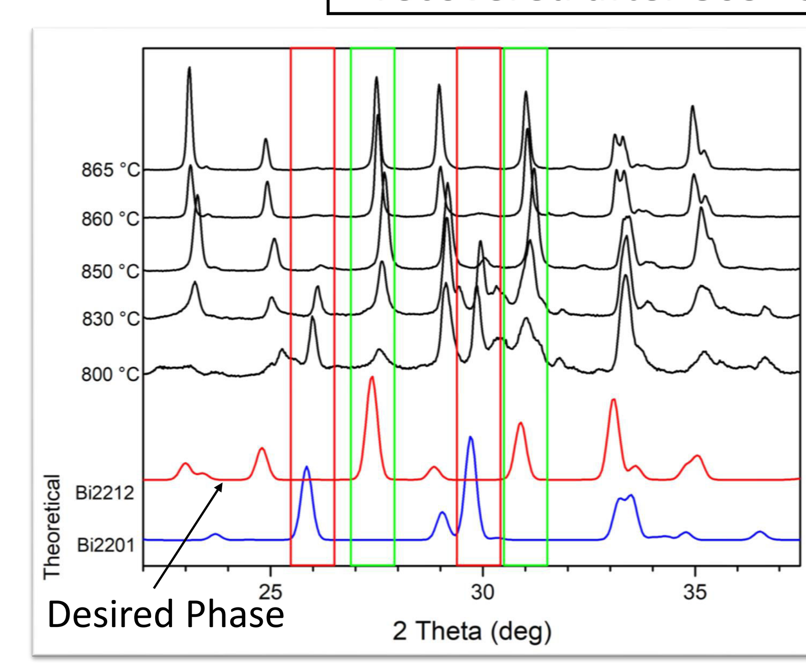
1. Dry, mix, and decarboxylate (700 °C, 24 hours) raw materials (Bi_2O_3, PbO, $SrCO_3$, $CaCO_3$, Y_2O_3, CuO)
2. Grind and heat for solid state reaction (72 hours)
3. Take XRD and check the present phases
4. If purity is not high enough, repeat 2 and 3 at a higher temperature
5. Grow single crystal in Traveling Solvent Floating Zone Furnace (TSFZF)
6. Analyze sample with XRD, PPMS, and ARPES



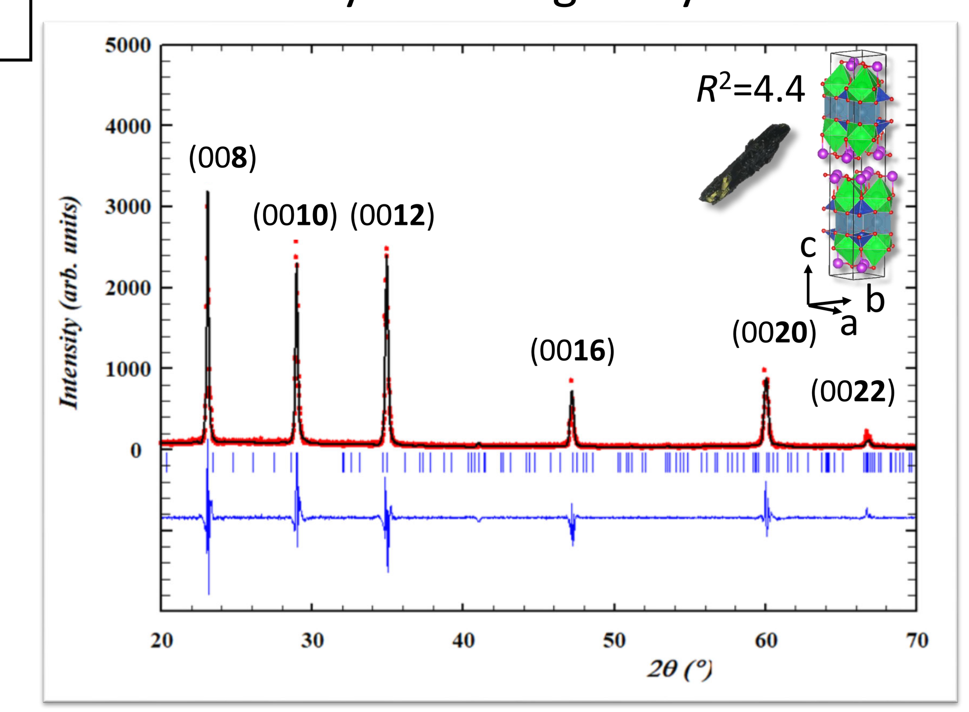
Results and Discussion

Powder XRD

✔ Bi2212 phase recovered after 865 °C

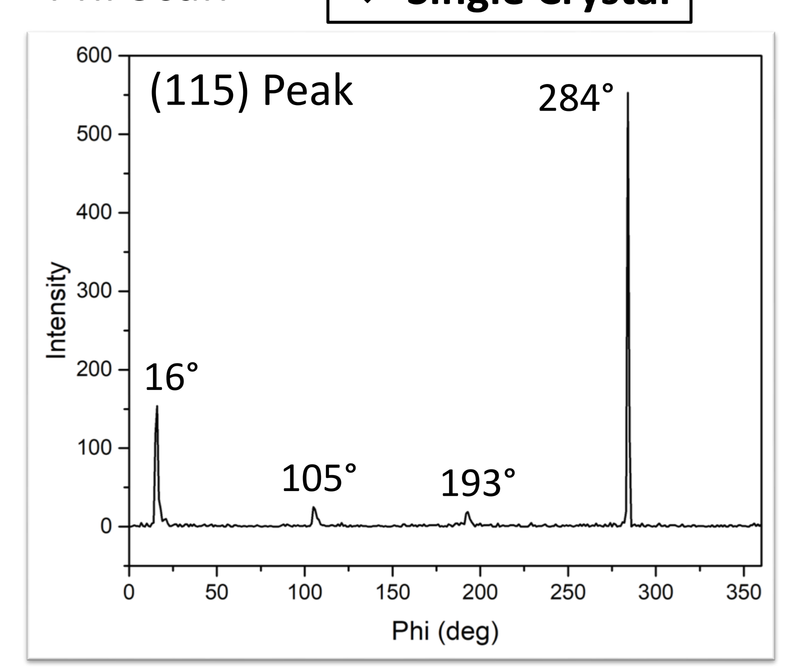


Rietveld Analysis of Single Crystal XRD



Phi Scan

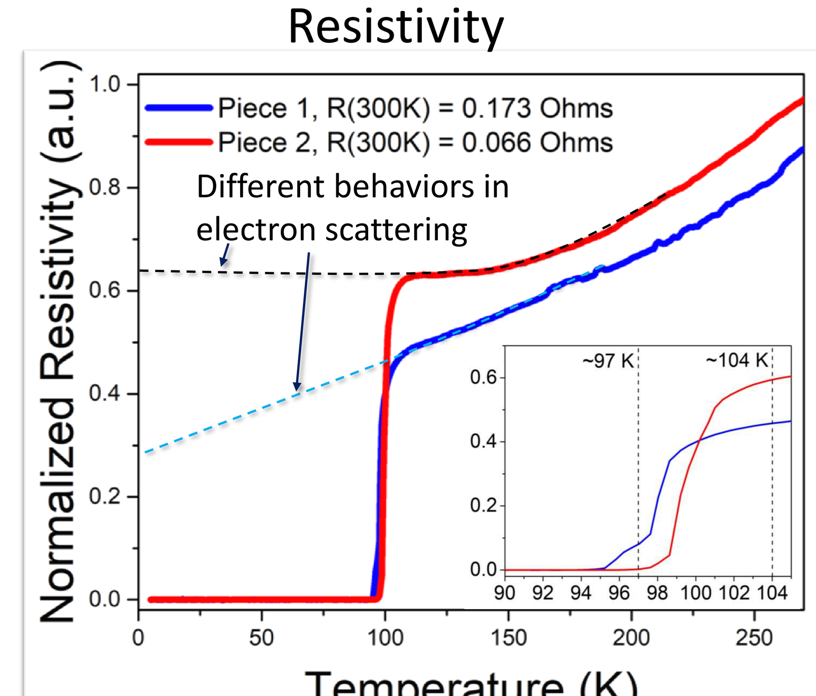
✔ Single Crystal



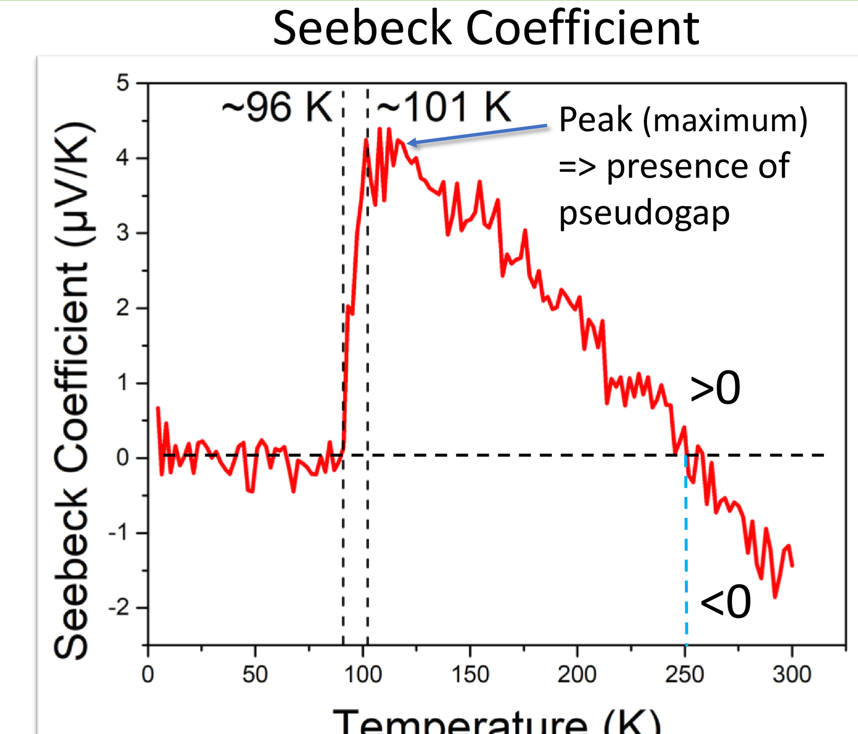
✔ Single crystal shows high crystallinity and pure Bi2212 phase

- Powder XRD shows only desired (Bi2212) peaks after heating to 865 °C, suggesting a **high purity powder**
- Single crystal XRD demonstrates **high crystallinity** and Rietveld analysis displays **pure Bi2212 phase**, with R^2 = 4.4 (R_{wp} = 21.7, R_{exp} = 10.0)
- Phi scan shows sharp peaks with 4-fold symmetry (90° separation) => prepared sample has **single crystal** qualities

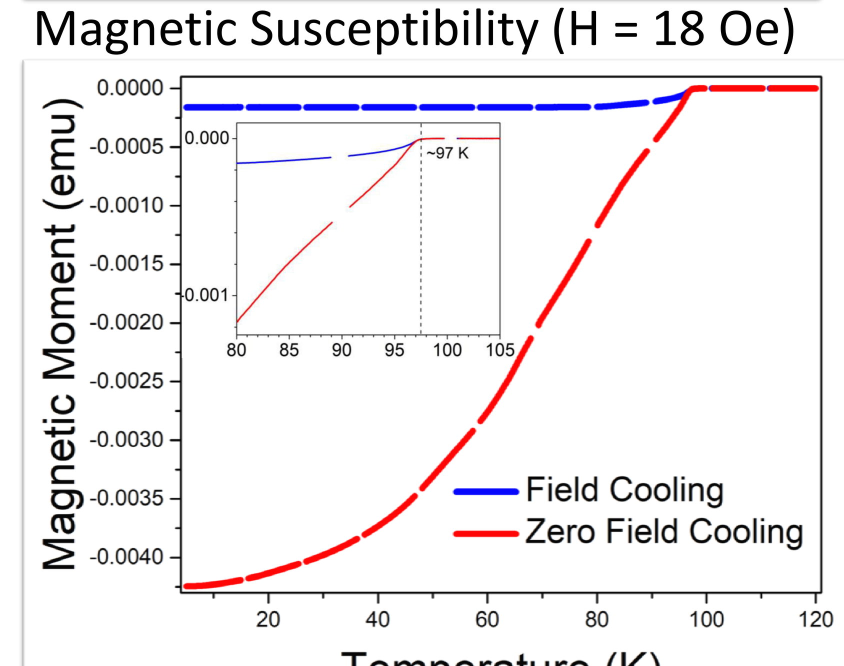
Resistivity



Seebeck Coefficient



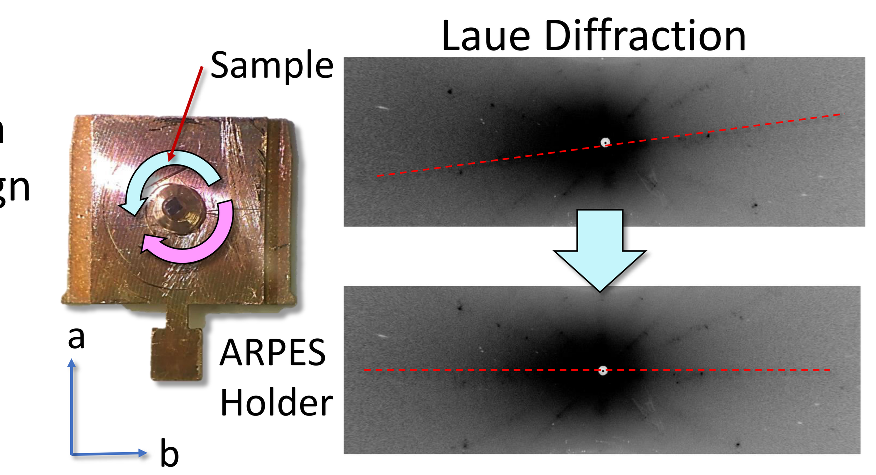
Magnetic Susceptibility (H = 18 Oe)



✔ High critical temperature (~97 K)

- Resistivity, Seebeck Coefficient, and Magnetic Susceptbility measurements show superconducting character at same, high temperature, suggesting **optimal doping** (target)
- T_c(onset) = **~104 K**
- T_c(downset) = **~97 K**

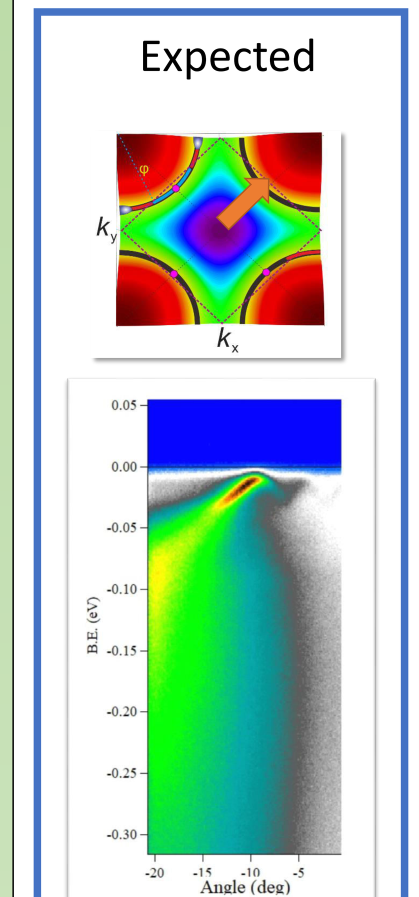
ARPES – Sample Alignment:



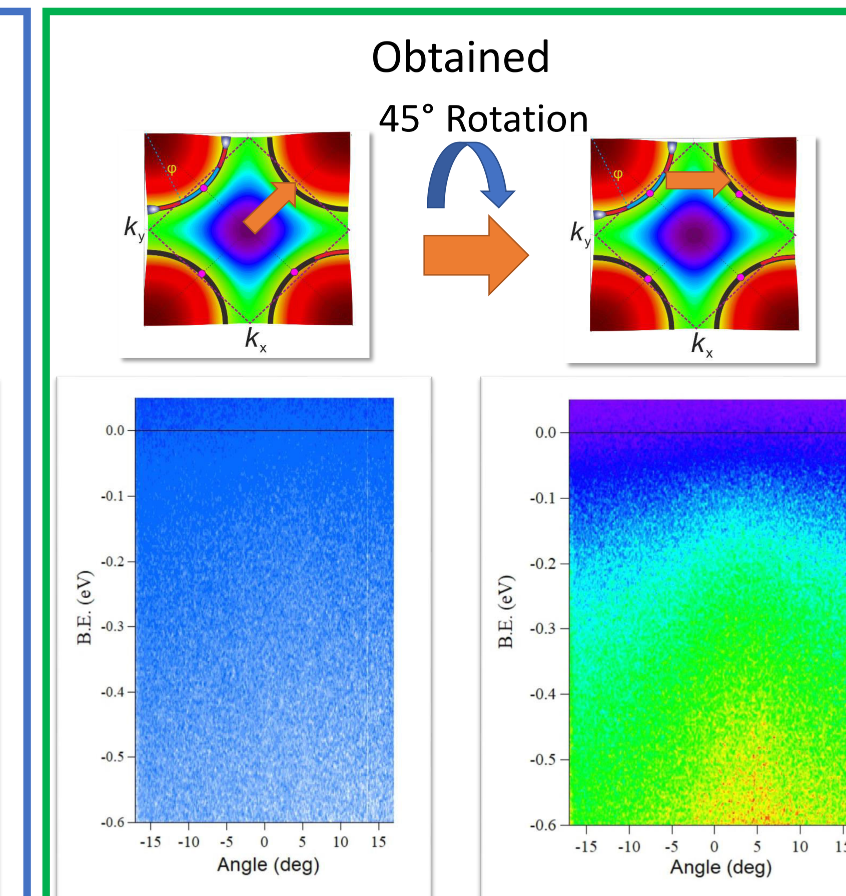
Laue Diffraction was used to align the sample for ARPES measurement

ARPES – Measurement (Xe discharged plasma lump, 8.47 eV):

Expected



Obtained



- Unfortunately, **no dispersion pattern** observed (300 K)
- Reason unknown

Conclusions

- A high-quality single crystal sample of Bi2212 in the optimally-doped regime was successfully obtained
- An energy-momentum dispersion pattern was unable to be identified using ARPES for unknown reasons

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

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