Synthesis and Measurement of the Cuprate Superconductor $HgBa_2CaCu_2O_{6+\delta}$

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Background

The cuprates are a class of high temperature superconductors characterized by crystal structures containing copper-oxygen planes. The cuprates exhibit significantly higher T_c values than conventional superconductors, and also have a very complicated phase diagram based on temperature and sample doping, as shown in figure 1. The mechanism behind superconductivity in the cuprates is not yet understood, and several of the other phases on the diagram, especially the pseudogap and strange metal phases, exhibit very anomalous properties. Thus, the goal of this project, and of studying the cuprates in general, is to probe the phase diagram in order to better understand the properties of the cuprates and what causes high-temperature superconductivity.

Growth and Characterization

Hg1212 is a double layer mercury-based cuprate which is ideal for experimental study because it has the highest T_c of any known double layer cuprate and has a simple tetragonal crystal lattice. To produce single crystal samples of Hg1212, copper oxide and barium nitrate powders are ground to produce a precursor that is sintered overnight. The precursor is then ground with calcium oxide powder and put into a zirconium growth crucible. The crucible is then placed into a quartz tube with mercury oxide and magnesium sulfate crystals, which introduce impurities to help crystal formation. The tube is then welded closed under a vacuum. Next, the tube is placed in a furnace for several days to allow crystal formation. After being removed from the furnace, the tube is broken and the boule is placed in a vacuum chamber until it can be searched through for crystals.

Once the crystals have been taken out, they can be characterized using a Quantum Design Inc. MPMS instrument, in order to measure the T_c and quality of the sample. One such measurement is shown in figure 2. Once the T_c of the sample is known, the sample can be annealed under a variety of conditions in order to both increase the quality of the sample and change its doping level, allowing different parts of the cuprate phase diagram to be explored.

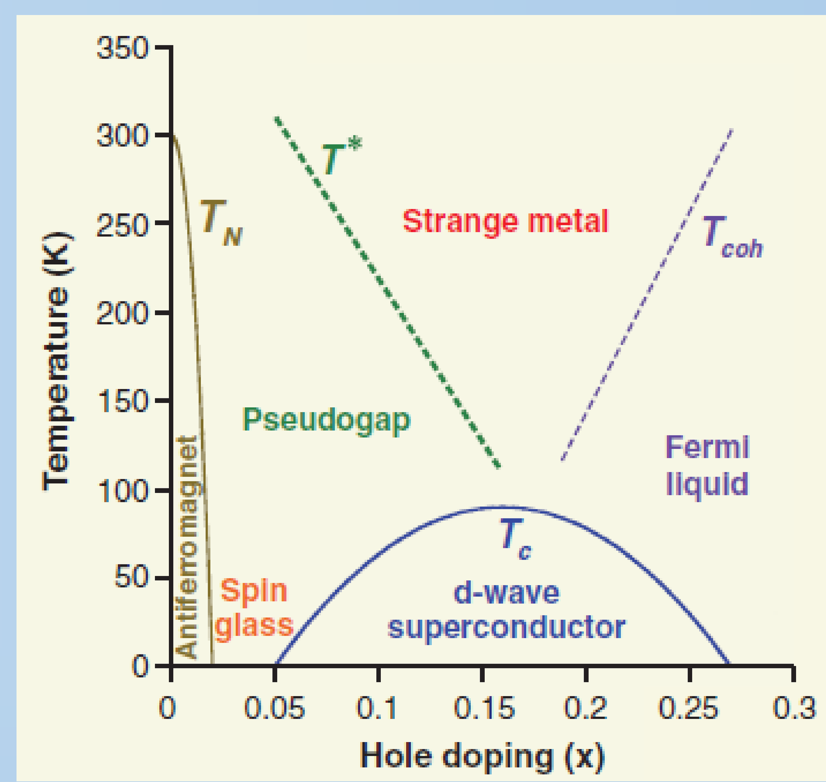


Figure 1 (Left) – General temperature and doping dependent phase diagram for a cuprate superconductor.

Figure 2 (Below) – MPMS characterization measurement for an as-grown sample of Hg1212. The small FC/ZFC ratio and the broad superconducting transition indicate that this sample is not of very high quality.

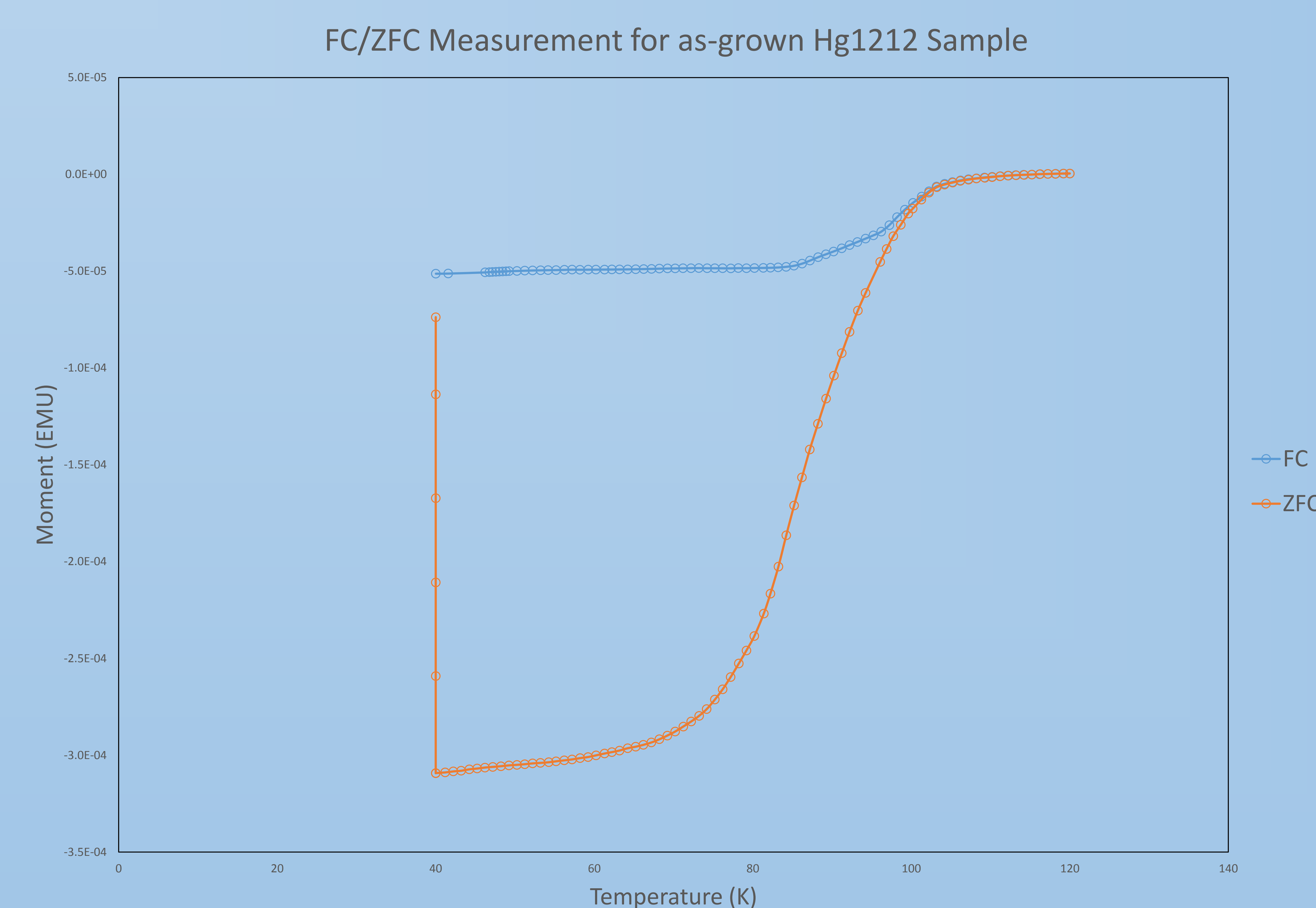
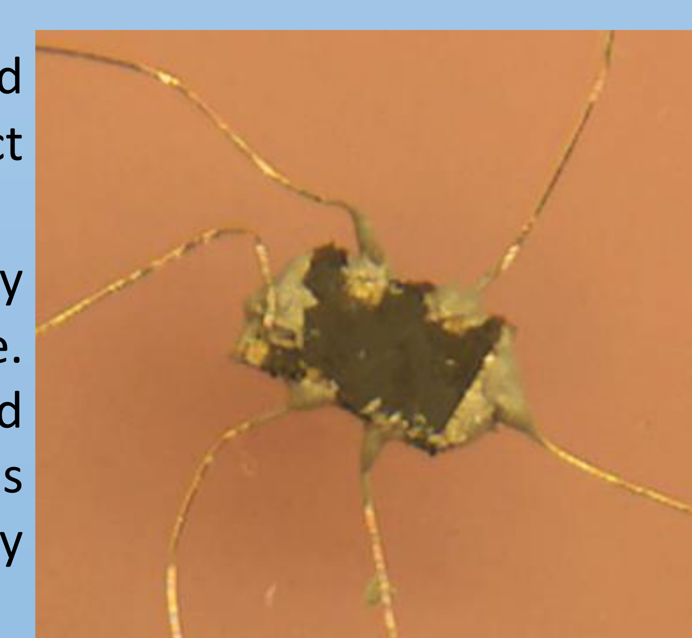


Figure 3 (Left) – A masked Hg1201 sample with six contact points left uncovered.

Figure 4 (Right) – A fully contacted Hg1201 sample. After the silver paste is baked dry and the contact resistances are tested, the sample is ready to be used for measurement.



Acknowledgements:

This work was supported by the University of Minnesota Office of Undergraduate Research, the by U.S. Department of Energy, Office of Basic Energy Sciences.

Preparation for Transport

Once a sufficiently high-quality sample has been obtained, it is then prepared for transport measurements. First, the sample is cleaved, or cut under a microscope to ensure the crystal surface in the a-c plane is flat. Next, the sample is masked, or covered with aluminum foil and masking tape in such a way that only six contact points on the sample remain uncovered. A cleaved and masked sample is shown in figure 3. Then, the sample is gold-sputtered, covering the entire thing in gold so that once the masking is removed, the six required contact points will be covered in conductive gold pads. Finally, the sample is contacted by using silver paste to attach gold wires to the contact points and then baking the sample to harden the silver paste. A fully contacted sample is shown in figure 4. Once a sample is fully contacted, if the resistance of each contact point is sufficiently low, the sample is ready to be used in a variety of different measurements to try to better understand the different parts of the cuprate phase diagram.

Future Work

My original proposal was to perform planar resistivity and Seebeck effect measurements on crystals of Hg1212, extending previous work done in the Greven group on Hg1201. Sufficiently large and high quality samples of Hg1212 have not yet been obtained, but new growth ideas have shown promise and high quality samples should be available soon. I plan to continue synthesizing Hg1212 crystals and annealing them to a variety of doping levels, and when high quality samples are produced, use the transport preparation skills I have gained to perform planar resistivity and Seebeck effect measurements and to look for correlation between those two measurements in Hg1212 over a wide range of temperatures and dopings.

References:

1. Y. Li *et al.*, *Unusual magnetic order in the pseudogap region of the superconductor $HgBa_2CuO_{4+\delta}$*. Nature **455**, 372 (2008).
2. M. J. Veit, *Transport measurements of the cuprate superconductor $HgBa_2CuO_{4+\delta}$*. University of Minnesota Undergraduate Honors Thesis (2014).