Optimizing Crystal Growth of the Cuprate Superconductors $HgBa_2CuO_{4+\delta}$ and $HgBa_2CaCu_2O_{6+\delta}$

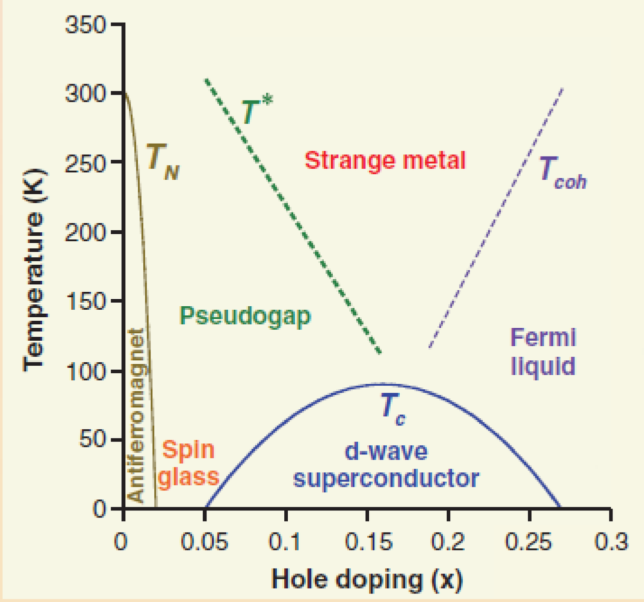
Jacob Freyermuth
Greven Lab – University of Minnesota Department of Physics and Astronomy

Abstract

The crystal growth processes of the mercury-based cuprate superconductors $HgBa_2CuO_{4+\delta}$ (Hg1201) and $HgBa_2CaCu_2O_{6+\delta}$ (Hg1212) were studied in order to learn to grow high-quality samples and to optimize the growth process. Grown samples were characterized using a Quantum Design, Inc., MPMS instrument to measure their superconducting transition temperature (or T_c) and estimate sample quality. Many samples of both Hg1201 and Hg1212 were successfully created, including some large samples of Hg1212. However, the quality of grown samples was often low, and studying how to reliably create higher quality samples is an important topic for continuing research.

Background

Cuprates are a class of unconventional superconductors characterized by crystal structures containing copper-oxygen planes. First discovered in 1986, the cuprates have been an active area of study since then, because they have higher T_c values than any other currently known superconductors, and they have a very unique and complicated phase diagram (**Figure 1**). It is unclear how the superconductivity in the cuprates arises, and the phases above the superconducting dome have some unusual and unexpected properties. The goal of studying the cuprates is to better understand this phase diagram, in order to eventually understand the mechanism behind superconductivity in the cuprates.

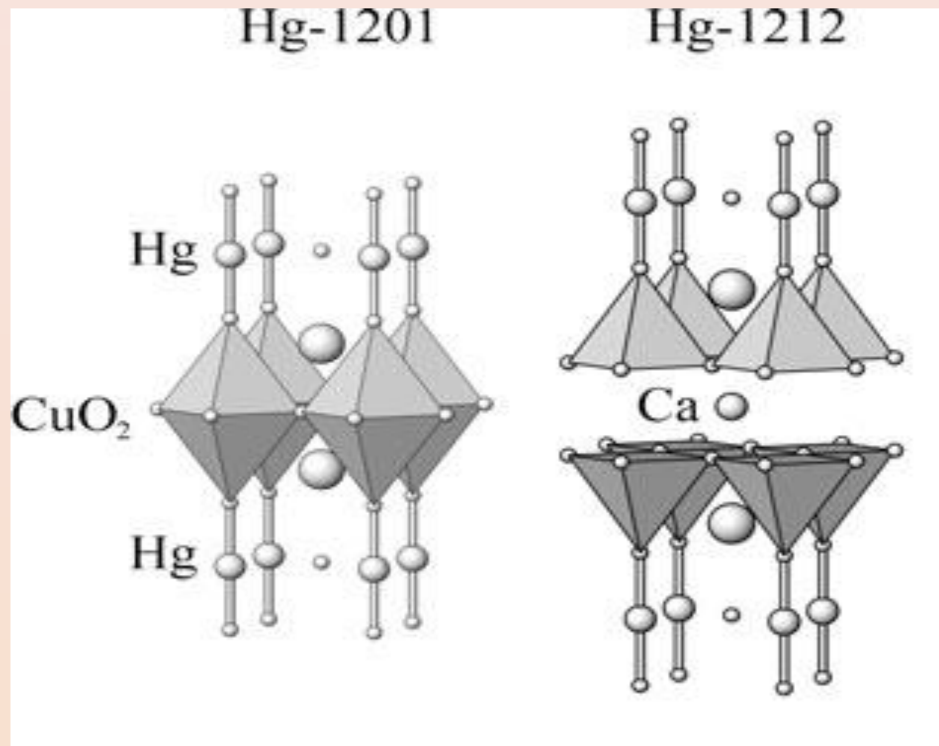


Growth and Characterization

Hg1201 and Hg1212 are two mercury-based cuprates that are ideal for experimental study, as they have very high T_c values and simple tetragonal lattice structures. To grow samples of these compounds, we first grind a precursor consisting of copper oxide and barium nitrate powders, and then sinter the powder overnight. For Hg1212, calcium oxide powder is ground into the mixture after sintering. The sintered precursor is put in a growth crucible with mercury oxide powder and magnesium sulfate crystals, then welded into a quartz tube under a vacuum. This quartz tube is placed into a furnace for several days and then removed and broken. The boule is then placed in a humidity box until it can be broken and searched for crystals. Once the crystals have been taken out, they can be characterized using a Quantum Design Inc. MPMS instrument, which cools the sample close to absolute zero under different magnetic fields in order to measure the T_c and quality of the sample. Once the T_c of the sample is known, the sample can be annealed under a variety of conditions in order to change the doping of the sample or used for measurements of other characteristics of the crystal, such as the Hall or Seebeck coefficients.

Hg1201 Growths

Figure 2 - The tetragonal lattice structures of Hg1201 and Hg1212 are shown. Hg1201 is a single-layer cuprate, meaning that there is one copper-oxygen layer between layers of mercury and barium ions. Hg1212 is a double-layer cuprate, meaning there are two such copper-oxygen layers.



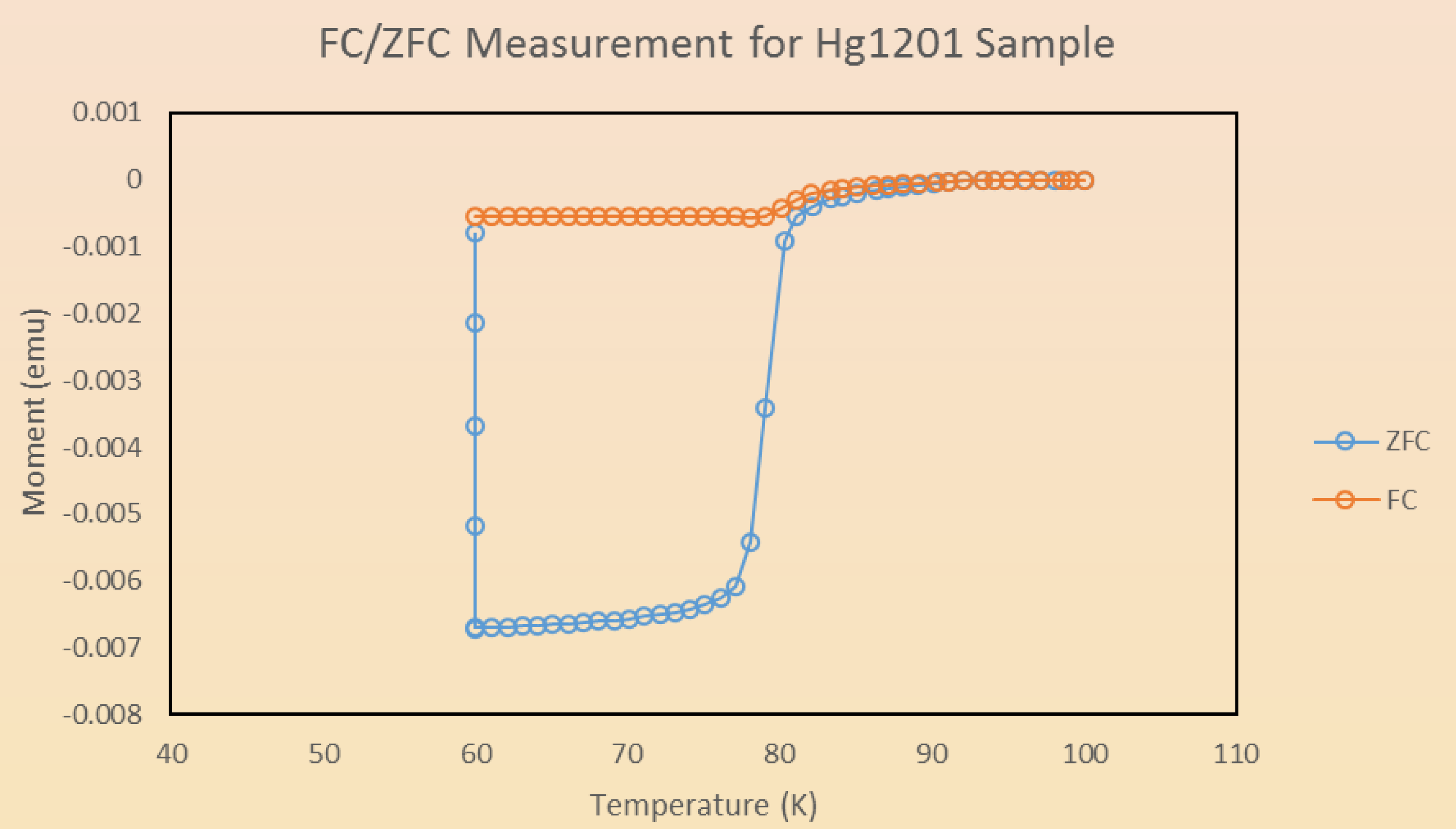


Figure 3 – Field-cool (FC) and zero-field-cool (ZFC) measurements for an as-grown sample of Hg1201. The sharp change in magnetic moment represents the transition between superconducting and non-superconducting states. The T_c of this sample is around 80 K. First, the sample is cooled under a magnetic field (FC; upper data points), then again with no magnetic field (ZFC; lower data points). In theory, the diamagnetic moment at temperatures below T_c should be the same for FC and ZFC measurements, and taking the FC/ZFC ratio gives an estimate of the quality of the sample. The FC/ZFC ratio of this sample is about 10%, which indicates that the sample is of relatively low quality. The reason for samples being of lower quality is a source of continuing investigation.

Hg1212 Growths

Until recently, there had been much less progress in growing samples of Hg1212. However, we have been able to generate more consistent growths of Hg1212 crystals. Although these growths have yielded more and larger crystals than past attempts, we have not yet made enough progress in increasing the quality of samples generated.

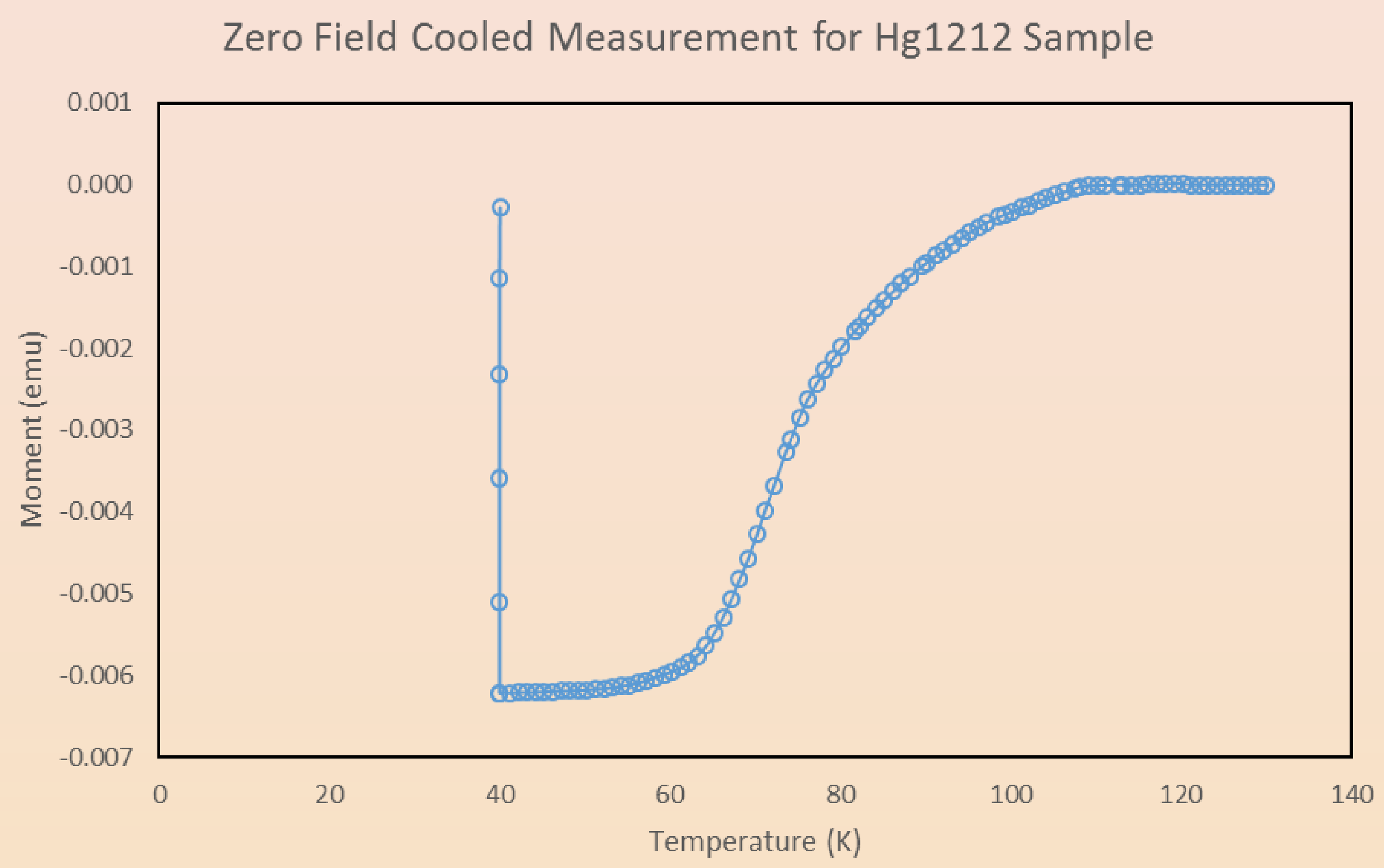


Figure 4 – ZFC measurement of an as grown sample of Hg1212. This sample has a T_c of about 75 K. However, the transition between superconducting and non-superconducting states is very broad, which indicates a low-quality sample.

Conclusion and Future Research

Overall, I was successful in learning how to generate and characterize Hg1201 and Hg1212 crystals, and some progress was made by standardizing the growth procedure to eliminate inconsistencies between growths. Although this has allowed for better growths in recent months, we have not yet been able to match the quality of Hg1201 crystals that have been produced in the past, or to bring Hg1212 production to the same level. Potential improvements to the growth process, including creating better precursor, not exposing the sintered precursor to air, and using thicker quartz tubes in order to achieve a higher pressure inside the furnace, among others, are currently being studied in order to continue increasing the size and quality of samples and allow for more progress toward a deeper understanding of superconductivity in the cuprates.

Acknowledgements

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References

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