CRYSTAL GROWTH AND CHARACTERIZATION OF $La_{2-x}Sr_xCuO_4$ CUPRATE SUPERCONDUCTOR

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Introduction

Superconductivity was first discovered by physicist Kamerlingh Onnes in 1911 when he cooled mercury to 4.19 Kelvin [1]. Superconductivity is the interesting property of matter which demonstrates zero electrical resistance and the expulsion of magnetic fields from its interior after the material is below some critical temperature T_c. The goal has been to raise this critical temperature to more manageable values, and high-transition-temperature superconductors became a reality after Alex Müller and Georg Bednorz discovered lanthanum-based copper oxide (cuprate) had a critical temperature near 30 Kelvin [2]. Using cuprate materials the critical temperature has been raised such that liquid nitrogen, with a temperature near 77 K, can be used as a coolant and allowed for more practical usages of the materials.

$La_{2-x}Sr_xCuO_4$ (LSCO)

This is a cuprate compound that effectively has an alternating planar structure of CuO and La(Sr)O (Figure 1). This material is hole doped, meaning that there is a scarcity of electrons and that positive charge is able to flow freely. This occurs through the chemical substitution of the trivalent La with the divalent Sr to create a controllable charge imbalance. The temperature dependent properties can be well described by a standard phase diagram for doped cuprate materials (Figure 2), which demonstrates a dependence on doping level and temperature for the superconductivity range.

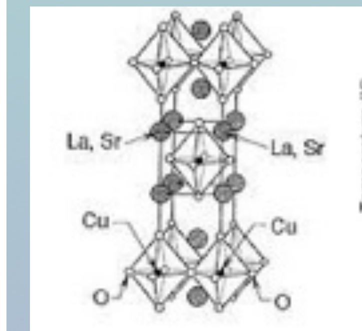

Figure 1: LSCO structure with CuO_2 and La,Sr planes

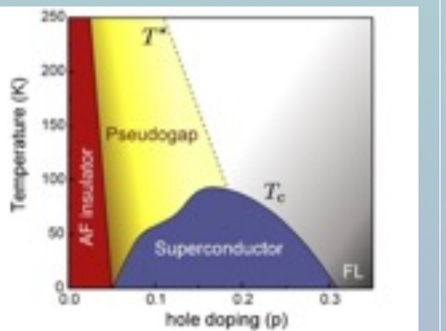

Figure 2: Standard phase diagram for a doped cuprate

SQUID Measurement

Superconducting Quantum Interference Device (SQUID) magnetometry is a highly sensitive probe of magnetism that is used to determine the diamagnetic signal of superconducting samples as a function of temperature. This is used to detect the sensitive magnetic fluctuations within the given materials in order to determine their magnetization as a function of temperature. This is particularly useful since it is effective at reducing magnetic background noise and precisely placing the phase transition temperatures of the material.

Procedure

Single crystals of LSCO were grown using the traveling-solvent-floating-zone (TSFZ) crystal growth technique. This synthesizes a crystalline cuprate material by targeting a melt area of a feed rod and re-solidifying it with a controlled ratio of LSCO solvent, which has a rich content of CuO_2 [3]. After this crystal growth is completed there is a large sample to inspect for single crystal formation using Laue X-Ray diffraction (Figure 3). This technique is versatile and has had success growing a number of cuprate crystals previously. To remove the extra oxygen formed during the growth, the parent compound La_2CuO_4 and very underdoped LSCO were annealed in Ar at 800 °C for 20 hours. For superconducting LSCO, the samples were annealed in Air at 800 °C for 40 hours to remove thermal stress.

Figure 3: Orientation of single crystal A-B plane. C-axis normal to surface

Laue X-Ray Diffraction

This method of X-Ray crystallography uses a continuous range of wavelengths and directs them at a crystal where they will Bragg scatter off of the crystal planes. This will create a pattern of diffraction spots arranged around the crystal indicate the structure of the crystal from pattern and orientation. This creates a "star shaped" pattern that can be arranged to yield the precise orientation of the sample (Figure 4). Additionally, the quality of the crystal sample can be determined from the "blurriness" of the image since that wold indicate two or more crystal planes overlapping.

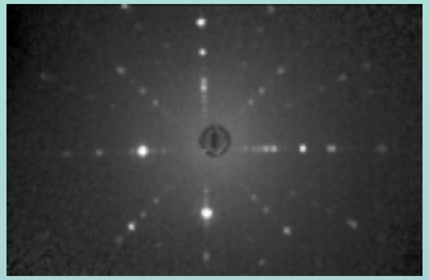

Figure 4: Laue X-Ray diffraction pattern for single crystal LSCO

Results

The parent compound and x=0.07 sample were able to be tested. Thus, the results for the post-annealed LCO samples were that it observed no superconducting character from (0, 350) Kelvin, but showed a clear Neal temperature transition around T_N~320K (Figure 5). For x=0.07 sample, it shows a clear superconducting transition around T_c~17K (Figure 6). This T_c is not considered high-temperature superconduction, which would optimally have transition temperatures at the temperatures of liquid nitrogen (~77 K). However, this is critical to establishing optimal doping levels to use for LSCO.

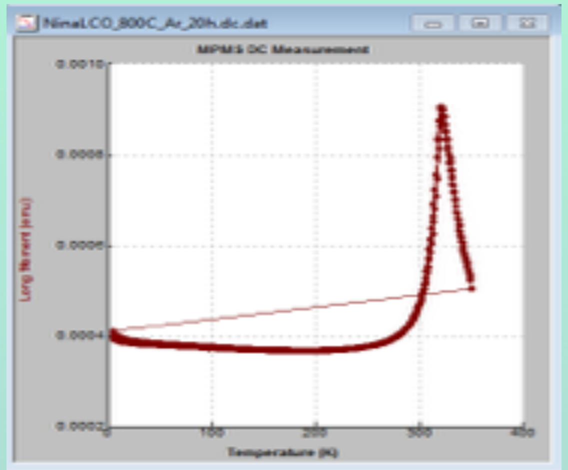

Figure 5: SQUID measurement LCO; Neal temperature transition at ~320 K

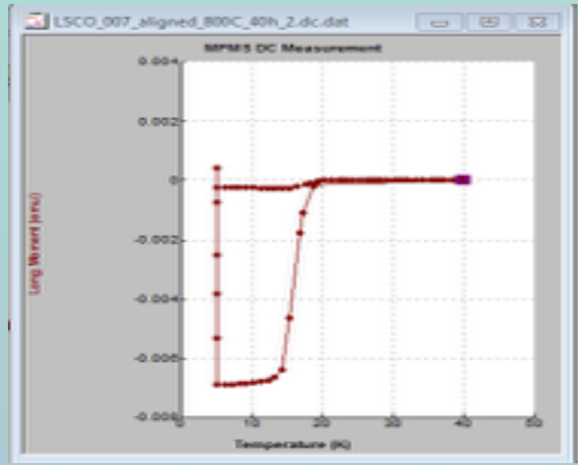

Figure 6: SQUID measurement for LSCO x = 0.07; Superconducting transition temperature at ~17 K

References

[1] H. K. Onnes, Commun. Phys. Lab. Univ. Leiden **12**, 120 (1911).
[2] J. G. Bednorz and K. A. Müller, Z. Physik B **64**, 189 (1986).
[3] H. A. Dabkowska and A. B. Dabkowski. "Crystal growth of oxides by optical floating zone technique." In Springer Handbook of Crystal Growth, pp. 367-391. Springer Berlin Heidelberg, 2010.
Figure 1: Crystal structure and phase diagram of the cuprate superconductor La2-xSrxCuO4. (LSCO) [Digital image]. (n.d.). Retrieved February 25, 2017
Figure 2: [Phase Diagram]. (n.d.). Retrieved February 25, 2017, from http://www.toulouse.lncmi.cnrs.fr/spip.php?rubrique149&lang=en