Superconducting Transition of Bismuth Strontium Calcium Copper Oxide (BSCCO)

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We measured the critical temperature of Bismuth-2223 Strontium Calcium Copper Oxide using various currents and resistances. Our average experimental critical temperature for BSCCO using $0.500 \pm 0.004A$ and $556.3 \pm 0.1\Omega$ is $119.71 \pm 11°K$, compared to Sykorova's value of $108°K$[4].

I. INTRODUCTION

Superconductivity, a phenomenon in which certain materials exhibit zero electrical resistance and the expulsion of magnetic fields at low temperatures, has been a subject of scientific curiosity and technological significance since its discovery over a century ago. Due to their unique properties, superconducting materials have important applications in MRIs, Maglev transportation, high-performance computing and many other technologies. Among the numerous superconducting materials discovered to date, Bismuth Strontium Calcium Copper Oxide (BSCCO)[2], belonging to the family of cuprate superconductors, is a well-known high-temperature superconductor. Discovery of such high-temperature superconductors can propel humanity into a realm of efficient technologies. In this experiment, we verified the superconductivity of BSCCO, specifically with Bi-2223, and measured the critical temperature at which it exhibits superconducting properties.

II. THEORY

A defining property of superconductors is the loss of electrical resistance. The characterization of such materials can be found through resistive transition curves, where the resistance of the material is plotted against the temperature of the material. These plots play a pivotal role in identifying the critical temperature, T_c, which represents the threshold temperature below which a material enters its superconducting state.

Resistive transition curves tend to exhibit a rapid decrease in resistance as temperature decreases, reaching a minimum value at T_c, and then leveling off as the material becomes fully superconducting. In our experiment, we cooled the BSCCO to $\sim 75°K$ and allowed it warm up. One method to precisely determine the critical temperature involves analyzing the maximum gradient of the resistive transition curves. This point corresponds to the inflection point in the curve where resistance changes most rapidly. At this temperature, the transition from the normal resistive state to the superconducting state is most pronounced, and the material exhibits its full superconducting potential.

III. EXPERIMENT SETUP

Our experiment is similar to the four point probe experiment[1] in Figure 1. We, however, used a flat superconductor instead of a disk. A simple circuit with a $556.3 \pm 0.1\Omega$ resistor is used to track the resistance of the superconductor. The temperature of the superconductor is measured using a Platinum-100 resistance temperature detector.

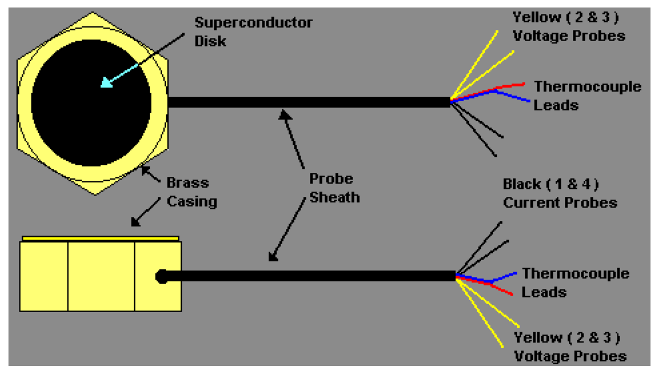

FIG. 1. Schematic of the experiment[1]

Prior to each trial, BSCCO was initially cooled using liquid nitrogen until the resistance of the material stabilizes around 20.2Ω or the temperature is at around $77°K$, the temperature of liquid nitrogen. About 100ml of 3mm liquid nitrogen-cooled glass beads were then placed in between the superconductor in order to slow down the warming up process of the superconductor, allowing for more data to be collected over a period of about 10 minutes.

As the superconductor warms up with the glass beads, the resistance of the temperature probe is collected to determine the temperature of the superconductor, using a table for Platinum-100 resistance temperature detectors[3]. We also fixed the current going into the superconductor. Several different values of current were used, but we found that $0.500 \pm 0.004A$ provided the most consistent results. Voltage of the superconductor is then used to calculate the resistance of the superconductor using Ohms' law, $R = V/I$. Voltage and resistance of the temperature probe were collected at 1 second intervals until the superconductor warms up past the critical temperature, when the resistance of the temperature probe approaches 70Ω.

IV. RESULTS AND DISCUSSION

A total of 9 trials were conducted for currents of $0.500 \pm 0.004A$. Critical temperature of BSCCO was calculated for all trials and aggregated to yield an average experimental value of $119.7 \pm 11.0°K$, at a 95% confidence. Results from every trial can be seen in Figure 2.

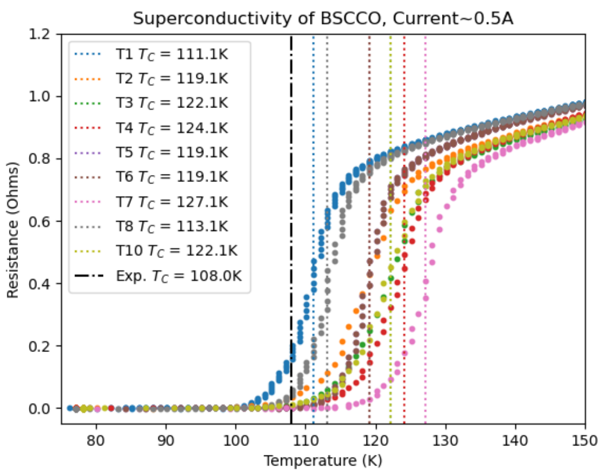

FIG. 2. Resistance (Ω) vs. Temperature ($°K$). Results from 9 trials, where currents are $\sim 0.5A$

Our best trial can be seen in Figure 3 where 0.250A current was used. Trial 9 achieved an impressive 1% deviation from Sykoraova's value. As seen in Figure 2, a critical temperature of $111.1°K$ was also measured for 0.500A. The associated error bars for Trial 9 were calculated using equations 1, 2 and 3. The error bars are small due to the precision of the voltmeters and ammeters.

$$\left(\frac{\Delta R}{R}\right)^2 = \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 \tag{1}$$

where measurement errors are,

$$\Delta V = 0.001875V \tag{2}$$
$$\Delta I = 0.001A \tag{3}$$

There are several systemic error that we are aware of. First, the humidity and temperature in the room may have affected the quality of data. Data was collected over 4 weeks, and a change in temperature and humidity of the room can vary from week to week. We, however, do not suspect that the state of the room contributes much to the errors in the experiment.

Background voltage is another variable for error. A background voltage of about 0.003V is present in the data collection phase. Theoretically, the voltage is 0 due to the lack of electrical resistance from the superconductor at low temperatures. We have subtracted the background

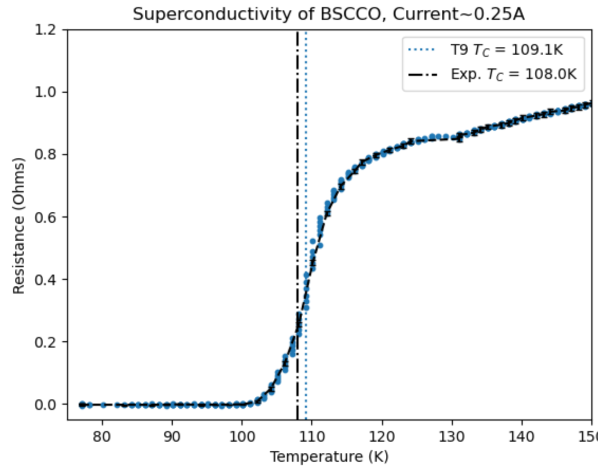

FIG. 3. Resistance (Ω) vs. Temperature ($°K$). Results from Trial 9, where current is $\sim 0.25A$

from our data, but since critical temperature is measured using gradients, a linear additive transformation will not affect the gradients.

Another inconsistent factor in the experiment is the time between removing the BSCCO from the container of liquid nitrogen, where it was cooled, and placing it onto the cooled glass beads. The time varies from trial to trial, but it should not affect our results since the shape of the superconductivity curve is still preserved. Maximum gradient is indifferent of rapid change in temperature at lower temperatures.

One area of concern is variance of our results. Currents between $0.25A$ and $0.75A$, as well as resistors of 500 to 1000Ω were used to reproduce the experiments. The same spread of critical temperatures was still observed, indicating unaccounted systemic error, potentially in the accuracy of scientific instruments, or the temperature sensitivity of the heat bath.

V. CONCLUSION

The average experimental value for the critical temperature of Bismuth-2223 Strontium Calcium Copper Oxide is $119.71 \pm 11°K$. While properties of superconductivity is observed, the average experimental value is about $10°K$ from Sykorova's value of $108°K$[4]. It is, however, within the 95% confidence band of our results. There are several systemic error associated with the experiment, though many negligible. Through our results, we are able to verify the superconductivity of BSCCO.

ACKNOWLEDGMENTS

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