Lab Report #1: High Temperature Superconductivity

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October 1, 2012

Abstract

While ordinary superconductors usually change their conductivity level at around 30K, certain materials, referred as high temperature superconductors (abbreviated as high Tc from below), become superconductors at relatively high temperature. Two well-known such high Tc superconducting materials are BSCCO (bismuth strontium calcium copper oxide) and YBCO (yttrium barium copper oxide). This experiment measures and compares at which temperatures these samples become superconductors. Wavetek 27XT voltmeter and Keithley 181 Nanovoltmeter are connected to four-point probe samples to measure voltage and temperature over a period of time. The result shows that YBCO and BSCCO each become superconductors at 90K and 110K, both temperatures being significantly higher than the one of regular superconductors.

1. Introduction

Whereas many regular conductors cannot achieve zero electric resistivity due to their impurities and other similar characteristics, superconductors can reach exactly zero electric resistivity at low temperature [1]. Superconducting materials can carry current without losing energy, because the current in them are carried not by individual electrons but rather, by Cooper Pairs, or pairs of electrons [2]. As Cooper pairs allow electrons to move within a solid without being subject to energy-absorbing interactions, observers do not see any resistance in the material. Such Cooper pairs are formed only under certain temperature, called Critical Temperature [2]. Compared to the general superconductors that hit this critical temperature at around 30K, certain compounds are capable of forming Cooper pairs at relatively high temperature – thus referred as high Tc Superconductor – , such as at 138K [3]. Measuring this critical temperature for different types of high Tc superconductor is the main goal of this experiment.

Additionally, below the critical temperature, superconductor has the property of having **B** = 0 inside, i.e., it does not allow any magnetic field to flow into it. Due to such a property, once there is an outer source of magnetic field, superconductor induces internal microscopic magnetic dipole and corresponding internal magnetic field, repelling the outer source [2]. This in turn, produces the famous Meissner Effect. Although this effect has been tested along the measurement of critical temperatures of high Tc superconductors, it is not described below, as it is not the main focus of this experiment and report.

2. Instrumentation

In order to measure the temperature at which each sample becomes superconductor, the sample, DC power supplier, and ammeter are connected in series. Two separate voltmeters, one for measuring the voltage across the sample and the other one for measuring the temperature, are then connected parallel to the sample (Figure 1 below).

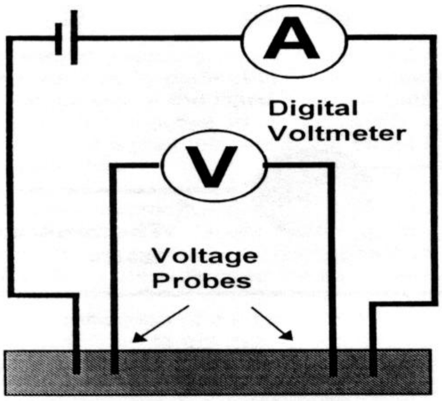

Figure 1: Apparatus Connection [2]

Samples of BSCCO (bismuth strontium calcium copper oxide) and YBCO (yttrium barium copper oxide) are manufactured by Colorado Superconductor Inc.; sample superconductor disks are embedded in a brass casing, which is then connected to four-point probe cables (Figure 2 below). Two probes are connected to Wavetek 27XT Voltmeter, and the other two are connected to Agilent 34401A 6 and 1/2 Digit Multimeter. There is an extra probe of thermocouple leads, which are connected to Keithley 181 Nanovoltmeter which indirectly measures temperature of the sample.

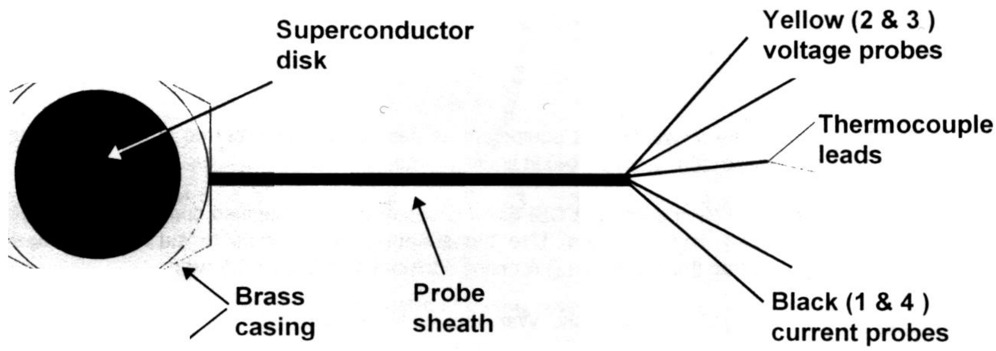

Figure 2: Four-Point Probe Sample [2]

3. Safety Issues

There are two possible sources of major injury: liquid nitrogen and DC power supplier. Liquid nitrogen must be poured slowly into the Styrofoam container, and the container should be separated from any temperature-sensitive lab apparatus. Placing and taking out the sample from liquid nitrogen also require extra care, as splashing or spilling may cause severe skin burn. Tweezers should be used at all times. Also, once taken out, cooled sample should be fixed to the table during the measurement period as it may easily get pulled or dropped due to connected cables. DC power supplier must have proper cable connections and all its knobs turned to zero-position before its power gets turned on.

4. Data Taking Procedure

I. Turn on the voltmeter, DC power supplier, and Keithley Nanovoltmeter. Arrange the power supplier to feed constant current below 0.5A.

II. Measure the regular voltage (from voltmeter) and temperature-voltage (from nanovoltmeter) across the sample at room temperature, and then place the sample in liquid nitrogen.

III. Let the sample cool down until the reading on the voltmeter is zero. This is equivalent to waiting until the resistance of the material becoming 0.

IV. Take out the sample, fix it onto the text table, and let it naturally return to its original temperature.

V. Starting from V=0mV, measure the increase of voltage across the sample and the corresponding temperature-voltage from the nanometer with constant step size (in this case, measurement was made every 0.1mV).

VI. Repeat V until the readings on both voltmeter and nanometer do not fluctuate anymore.

VII. Once all the measurements are recorded, use the table in "Experiment Guide for Superconductor Demonstrations" to convert the reading from nanometer to corresponding temperature. Divide regular voltage values by current as well, to convert them into resistance. Plot the results to analyze superconducting characteristics of two materials.

5. Data Analysis

For each sample, the measurement has been made twice, and the one with better recording timing and less error is chosen to be analyzed. For easier comparison, graph is attached on the next page (Figure 3). Edited short data tables are also attached below the graph (Figure 4) for referring to specific number values.

I. For BSCCO sample, applied constant current was 0.497A, and at room temperature, the voltage across the sample was 8.8mV, with its temperature-voltage (abbreviated as V_T in the following) being -0.30mV. Once the sample was cooled down in liquid nitrogen until its voltage dropped to 0, measurements of its voltage and temperature rise have been made with average step size 0.1mV. The measurement continued until the sample reached its initial voltage and stabilized; the span of single entire test was approximately 30 minutes. The sample stayed at 0mV for a while until the V_T rose to 6.21mV. Then its voltage started rising at a fast pace until 6.0mV, and slowed down again until its voltage fluctuation completely stopped at 8.9mV. Regarding the sudden jump (Figure 3 on the next page) in the sample's converted resistance between 0Ω and 0.01Ω, with corresponding temperature increasing from 80K to 110K (Figure 4), one can conclude that the temperature at which BSCCO becomes superconductor is at around 110K.

II. For YBCO sample, applied constant current was 0.499A, and at room temperature, its voltage across the sample was 6.5mV with its V_T being 0.40mV. Similar to BSCCO case, the sample was cooled down in liquid nitrogen until its voltage dropped to 0, and then measurements for voltage and temperature rise have been made with average step size 0.1mV. Whereas YBCO sample took longer to reach 0mV, the overall time YBCO sample took to stabilize back to its initial voltage (in room temperature) was significantly shorter than BSCCO sample as it took approximately 23 minutes. However, V_T at stabilized regular voltage (6.5mV) tended to fluctuate between 0.40mV and 0.32mV. The YBCO sample stayed at 0mV (corresponding V_T at 6.228mV) for a short time, then quickly jumped to 0.1mV (corresponding V_T at 5.58mV) and continued to increase until 5.0mV, where it started slowing down its pace until it reached 6.5mV. Again, close observation of the converted resistance jump (Figure 3 and 4 below) indicates that YBCO becomes superconductor at around 90K.

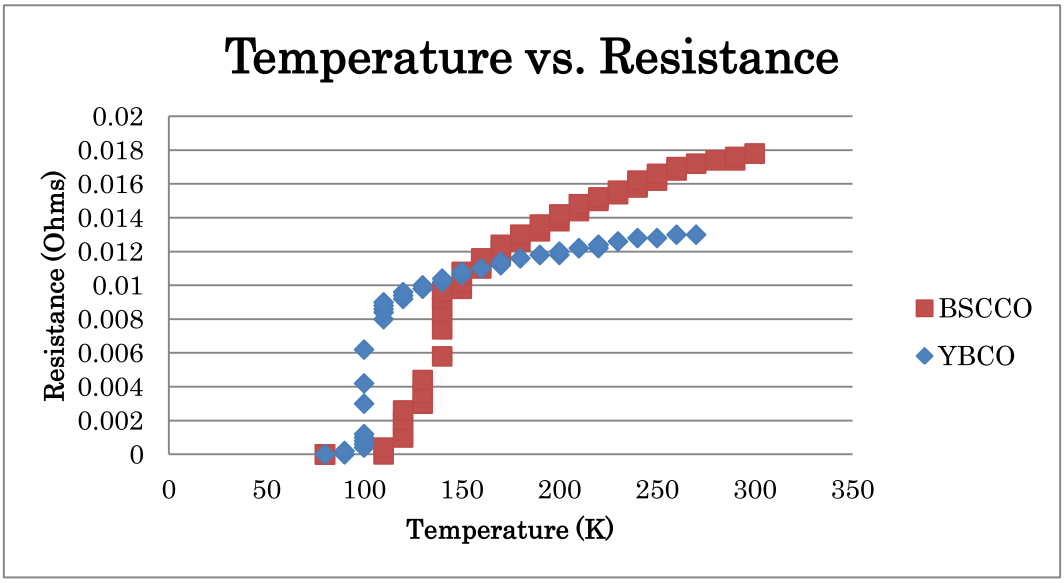

Figure 3: Graph of Temperature vs. Resistance for both YBCO and BSCCO

BSCCO2(Temp, in K)	Voltage(mV)	YBCO2(Temp, in K)	Voltage(mV)
80	0	80	0
110	0.2	90	0.1
120	1.3	100	3.1
130	2.2	110	4.5
140	4.8	120	4.8
150	5.4	130	5
160	5.8	140	5.2
170	6.2	150	5.4
180	6.5	160	5.5

190	6.7	170	5.7
200	7.1	180	5.8
210	7.4	190	5.9
230	7.8	200	6
240	8.1	210	6.1
250	8.3	220	6.2
260	8.5	230	6.3
270	8.6	240	6.4
280	8.7	250	6.4
290	8.8	260	6.5
300	8.9	270	6.5

Figure 4: Edited Table of Data

6. Conclusions

Although for each sample two tests have been performed, only the second measurements for each have been accounted for analysis. Two major reasons for discarding the first tests are the following:

I. The voltage of the sample increased very quickly, and for both samples the first trials were more about learning how to time it correctly to measure the increase with same step size; thus, both first trials have rather uneven voltage measurements.

II. The set of first tests also had cable connection troubles that became sources of errors. For both cases of samples, connected parts of probes were hanging closely to each other, occasionally contacting and causing fluctuations of voltmeter and nanometer. For YBCO sample, probes in fact got disconnected for a short time due to the weight of the sample itself, leading to the incorrect voltage reading afterwards.

The second set of tests, therefore, has been performed with modifications of apparatus setup and better timing, both fixed according to the results of the first set of tests. Regardless such modifications however, sources of error still existed, including the contact point of samples and the test table, room temperature changes, and the accuracy of reading data fluctuations. It is also true that the conversion range of V_T and actual temperature is rather huge; for instance, the entire range of 3.2 mV to 5.1 mV corresponds to 140K according to the table provided by Colorado Superconductor Inc.

The analysis of the second set of tests shows that the critical temperature of BSCCO is at 110K and that of YBCO is at 90K, both becoming superconductors at higher temperature compared to the regular superconductors. It also indicates that high Tc superconductors are not confined to one specific critical temperature; in evidence, BSCCO becomes superconductor at even higher temperature than YBCO does. From the graph above (Figure 3), one can also observe that BSCCO tends to increase its resistance after it returns to a regular material more than YBCO does.

7. References

[1] Wikipedia. "Superconductivity." *Wikipedia*. Wikimedia Foundation, 25 Sept. 2012. Web. 29 Sept. 2012. <http://en.wikipedia.org/wiki/Superconductivity>.

[2] Colorado Superconuctor Inc. *Experiment Guide for Superconductor Demonstrations*. Fort Collins: Colorado Superconuctor, 2007. Print.

[3] Wikipedia. "High-temperature Superconductivity." *Wikipedia*. Wikimedia Foundati on, 27 Sept. 2012. Web. 29 Sept. 2012. <http://en.wikipedia.org/wiki/High-tempe rature_superconductivity>.