Measuring the Temperature Dependance of Electrical Resistivity in $HgBa_2CuO_{4+\delta}$

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Introduction

$HgBa_2CuO_{4+\delta}$ (Hg1201), which has one of the highest transition temperatures among known superconductors, is part the class of high temperature superconductors known as cuprates. The cuprates form sheets of copper and oxygen, and the temperature dependence of the dc resistivity of the copper oxygen planes was measured for Hg1201.

Methods

Hg1201 crystals were first grown and annealed to adjust the oxygen content and therefore the transition temperature. The crystals were then characterized using a Magnetic Properties Measurement System (MPMS) to measure the magnetic moment of the samples as a function of temperature. Due to the Meissner effect, the samples had negative magnetic moments while in the superconducting state which counteracted an applied magnetic field and essentially zero moment when in the normal state. Therefore measuring the magnetic moment as a function of temperature showed the phase transition and gave an indication of the quality of the sample. An example of the resulting magnetic moment versus temperature graph is shown in Figure 1. High quality samples with sharp transitions were selected and resistivity measurements were carried out on them.

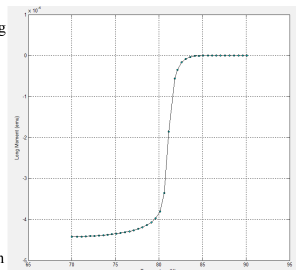
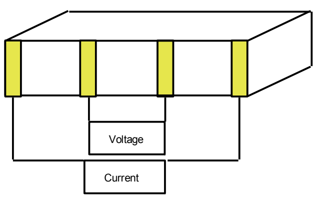


Figure 1: This shows an example MPMS measurement.

To prepare the crystals for resistivity measurements, they were first cleaved and four gold contacts were sputtered on the cleaved faces with the configuration shown in Figure 2. Gold wires were attached to the gold contacts using silver paint. The crystals were baked to anneal the silver paint and quenched to room temperature. The annealing conditions in this baking were the same as the initial long-term annealing conditions of the crystal to prevent any changes in the doping of the crystal. A picture of a contacted sample is shown in Figure 3.

The dc resistance of the samples were measured by connecting the contacts to a current source and a voltmeter as shown in Figure 2. The samples were inserted into the MPMS to control the temperature. The MPMS was used to vary the temperature from 40K to 380K and a current voltage curve was measured every 1K. The curve was obtained by varying the current on the current source from -5mA to +5mA and measuring the voltage across the sample every 1mA. The slope of the current voltage curve at a particular temperature was the resistance of the sample at that temperature and the resistivity was found by correcting for the dimensions of the individual sample.



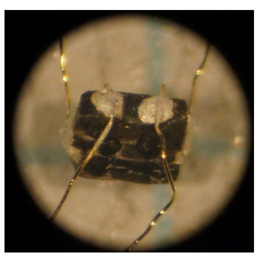
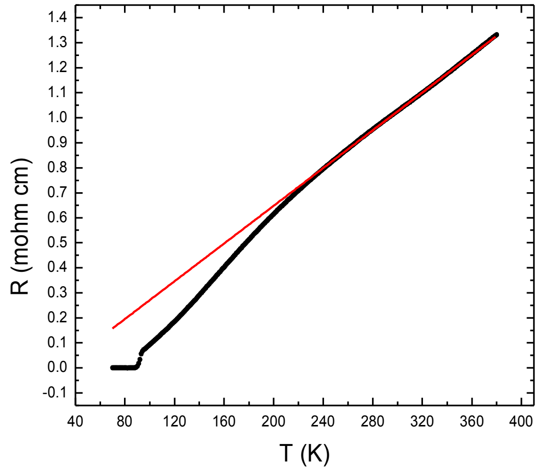


Figure 2 (left): This shows the configuration of the gold contacts as well as the connections to the voltmeter and current source
Figure 3 (right): This shows a fully contacted sample.

Analysis/Results



The resulting resistivity versus temperature graph for a Hg1201 sample with a transition temperature of 90K and a hole concentration of 0.12 is shown in Figure 4. It was observed that there was a linear relationship between temperature and resistivity at high temperatures. To determine the range of temperatures across which this relationship holds, a linear fit was performed for the high temperature data. The resulting fit equation was subtracted from the data, and the temperature at which this difference started to deviate from zero was the lower bound of the linear region. This temperature was called the pseudogap temperature.

It was also observed that there was a quadratic relationship between resistivity and temperature at temperatures just above the phase transition and below the pseudogap temperature. To estimate the temperature range for this region, the resistivity was plotted as a function of the temperature squared as shown in Figure 5. A linear fit was performed on the linear region in this graph and the range of temperatures was estimated by taking the difference between this fit equation and the measured data and observing where this difference deviated from zero.

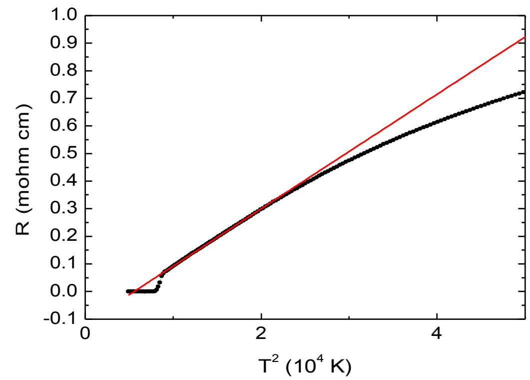


Figure 4 (top): This shows the measured resistivity versus temperature curve for Hg1201. The black curve shows the measured data. The red line shows the linear fit used to estimate the temperature at which the resistivity deviated from a linear relationship.
Figure 5 (right): This shows the resistance versus the square of the temperature. A linear region can be seen on this graph just above the transition temperature which indicates a quadratic relationship between resistivity and temperature. The black curve shows the measured resistivity and the red line shows the fit equation for the line region which was used to estimate the range of temperatures where the quadratic relationship holds.

Conclusions

Due to the size and shape of the samples, the resistivity was only obtained to within a 20% accuracy. However, when the resistances were normalized, many of the samples showed the same temperature dependence which indicates that the samples are electronically identical and the samples were homogeneous.

As expected, there was a sharp drop to zero resistance which corresponded to the superconducting transition found in the magnetic moment measurements of the samples. It was also found that at high temperatures, the resistivity increased linearly with temperature and at temperatures just above the superconducting transition, the resistance increased quadratically with temperature. The temperature below which the resistivity deviated from the linear relationship at high temperature is known as the pseudogap temperature and it was measured to be 250K for Hg1201 samples that had a hole concentration of 0.12. The temperature below which the resistivity deviated from the quadratic behavior was measured to be 170K for the same samples. The linear and quadratic behaviors provided evidence for new phases within those regions.

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