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Observation of Vortex Lattice Related Anomalies in Polycrystalline $YBa_2Cu_3O_{7-x}$ near the Superconducting Transition

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ABSTRACT

The d.c. I-V characteristic of polycrystalline $YBa_2Cu_3O_{7-x}$ high temperature superconductors (HTSC) is measured near the transition temperature (T_c). The T_c was found to be 90 K with a width of 2 K. The voltage was measured at various current values and with reversing the current. A difference in voltage was found for forward and reverse current directions near T_c. The observed directionality of the I-V characteristic can be understood in terms of quantized magnetic flux by the self-field of the current and the proximity junctions in these materials. This can also be understood qualitatively as due to the d-wave superconductivity. The measured dc voltage showed increased noise near T_c which is possibly related to 1/f noise due to the motion of Abrikosov flux lines.

Keywords: HTSC; Transition Temperature; 1/f Noise

1. Introduction

Superconducting materials have attracted interest in recent years [1-17]. Such materials show negligible electrical resistance and magnetic flux exclusion. Electrical and thermal properties of these materials have been studied below 100 K. These materials have technological applications which involve operation across or below the superconducting transition. Superconducting magnets, superconducting switches, temperature standards and switching devices are some examples. The transition temperature of $YBa_2Cu_3O_7$ which is a high temperature superconductor is about 90 K [8,9,12-16]. The effect of magnetic field on the specific heat anomaly near the superconducting transition is considerably different from the effect on conventional superconductors. It has been found that the specific heat peak associated with the superconducting transition mainly reduces in amplitude and broadens by the application of magnetic field. This is unlike the type-II conventional superconductors in which case the application of magnetic field shifts the specific heat jump at T_c to lower temperatures with practically very little change in the shape of the anomaly. There are also several other unusual behavior in the HTSC which is not yet understood [18]. Other studies to understand the microscopic filed distribution concerning the superconducting state has been carried out with high-field μSR [19]. Here we note that other materials such as CuO has also been studied in the context of theoretical understanding of HTSC [20,21].

2. Experiment

Electrical resistance measurement on polycrystalline $YBa_2Cu_3O_7$ was carried by an automated d.c. four terminal technique [16]. This setup is built around a closed cycle refrigerator. The $YBa_2Cu_3O_7$ sample was in the form of rectangular bar having dimension ≈ 1 × 2 × 11 mm^3. The sample was characterized as as been discussed elsewhere [8,9]. The electrical contacts made using silver paste had a resistance of 30 Ohms for the two current leads. The electrical resistance of the sample at 100 K was nearly 0.1 Ohms. The current was varied from 1 mA to 100 mA in steps using a Keithley model 224/2243 programmable current source. The dc voltage was measured using a Keithley model 182 sensitive digital voltmeter. A calibrated type D silicon diode thermometer was used in conjunction with a Leybold model LTC60 temperature controller to control and monitor the temperature of the sample site. The calibrated diode has a standard measurement accuracy of about 1 percent. The measurement was done as the sample was warmed from about 70 K. The HTSC has a superconducting transition (T_c) of 90 K and a width of about 2 K. At each temperature the current was increased from 1 mA to 100 mA in steps. For each current value, first the positive polarity of current was given and the voltage was measured. Then the current was made negative with the same value and the voltage was measured again. A systematic difference in voltage (dV) was found in the measurement.

3. Conclusion

Figure 1 shows dV as a function of temperature for $YBa_2Cu_3O_7$. It is seen that the difference in voltage or the directionality is enhanced near T_c. The directionality also increases as the current is increased from 1 mA to 100 mA. The observed directionality should be present in conventional superconducting materials but is enhanced in case of $YBa_2Cu_3O_7$. The theoretical understanding of the observed directionality is as follows. The total current through the superconductor can be written as follows:

$$\mathbf{J} = \mathbf{J}_s + \mathbf{J}_{diss} + \mathbf{J}_{disp} \quad (1)$$

where $\mathbf{J}_s$ is the superconducting current, $\mathbf{J}_{disp}$ is the displacement current and $\mathbf{J}_{diss}$ is the dissipation current. $\mathbf{J}_{disp}$ and $\mathbf{J}_{diss}$ becomes negligible with time and therefore only $\mathbf{J}_s$ need to be considered for the equilibrium I-V characteristic. Moreover, it is known that:

$$\mathbf{J}_s = -\text{const}\ \mathbf{A} \quad (2)$$

This gives rise to flux quantization and near the transition trapped quantized magnetic flux. This can give rise to observed directionality. Such directionality can arise possibly due to unconventional pairing [22]. The most discussed unconventional pairing is in the context of high temperature superconductors in which the pairing channel is l = 2 or d-wave. Such pairing states occur in various

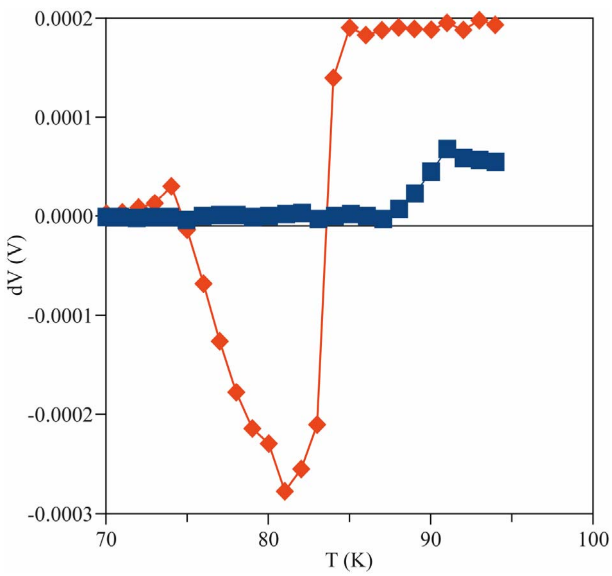

Figure 1. The temperature dependence of difference in voltage (dV) for $YBa_2Cu_3O_7$. The transition temperature T_c is nearly 90 K. dV is shown for two current values; 1 mA (■) and 100 mA (◊).

theories based on microscopic models which can show such unusual properties in the superconducting state.

The measured dc voltage also showed increased noise near T_c. This can possibly arise due to the motion of Abrikosov flux lines and has the nature similar to 1/f noise [23,24].

The HTSC $YBa_2Cu_3O_7$ has been studied by d.c. four probe electrical resistance measurement near the superconducting transition. A directionality in the d.c. I-V characteristic was observed. The observed directionality can be understood theoretically as due to trapped quantized magnetic flux. Theoretical understanding of such observation is also consistent with microscopic models based on d-wave superconducting state.

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