Magnetic properties of the 110K superconducting phase in Pb-doped Bi-Sr-Ca-Cu-O thin films

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Abstract

The relaxation of the remnant moment induced in a nearly single phase high Tc thin film of Pb-doped Bi-Sr-Ca-Cu-O has been investigated. Measurements reveal that the relaxation obeys a logarithmic time dependence for observation times up to 2000 seconds. The temperature dependence of the initial magnetization of the film and its decay rate are obtained. The initial magnetization monotonically decreases, however, the decay rate normalized by initial magnetization has a peak at approximately 14 K for an applied field of 500 gauss. The peak shifts to lower temperature for stronger magnetic field. These data are compared with existing data on other high Tc superconducting materials.

Introduction

The recent report of large flux creep in a single crystal of $YBa_2Cu_3O_7$ (YBCO)[1] has prompted investigation into the time dependence of remnant magnetization in that system and in other high Tc superconductors[2,3,4]. However, thin films of the oxide superconductors, particularly in the Bi system, have received relatively little attention. As the first applications of high Tc oxides will likely be in the form of thin films, it is important to examine the nature of magnetic relaxation in films. In this report the results of magnetic relaxation experiments on highly oriented, polycrystalline films of the high Tc phase in the Bi system are presented.

Sample preparation

The Bi-Sr-Ca-Cu-O (BSCCO) films were prepared on (100) MgO substrates by rf magnetron sputtering from a composite target and Pb was doped by means of an additional PbO target. The details of the sample synthesis have been reported elsewhere[5]. X-ray diffraction (XRD) results showed the film possessed a high degree of c-axis orientation perpendicular to the substrate surface and also indicated that the film was nearly single phase high Tc material. Very weak signals corresponding to the low Tc phase were observed in the XRD spectra. The thickness of the film used for this study was 0.85 microns. SEM photographs indicated that thin plate like crystals were stacked each other. The Tc (R = 0) was 106.2 K.

Experiment

The magnetic measurements were performed by means of a *Quantum Design* squid magnetometer in which the sample was cooled from room temperature in a field of approximately 2 gauss. A magnetic field was then applied parallel to the c-axis, maintained for ten minutes, and then removed. The time dependence of the resulting remnant moment was measured at several temperatures. Fields of 0.5 kgauss and 1 kgauss were used in this investigation.

Results and discussion

The relaxation of the moment was measured at several temperatures. The decay was linear in ln time during observation intervals of 2000 seconds. Some deviation from logarithmic dependence was observed after longer times. For magnetic relaxation observed over a period of 2000 seconds, a linear least squares fit to the data was made and the decay rate and initial (t = 1 second extrapolation) value of the magnetic moment (Mo) was calculated. Fig. 1 shows the initial value of the magnetic moment as a function of temperature for applied fields of 0.5 kgauss and 1 kgauss. It is seen that at temperatures between 3 and 14 K the temperature dependence of the initial magnetization Mo(T) is sensitive to the magnitude of the applied field. It is nearly linear when a 1 kgauss field is applied but

exhibits a rollover when the measurements are performed after the removal of a 0.5 kgauss field. At temperatures above 14K the two curves become very similar.

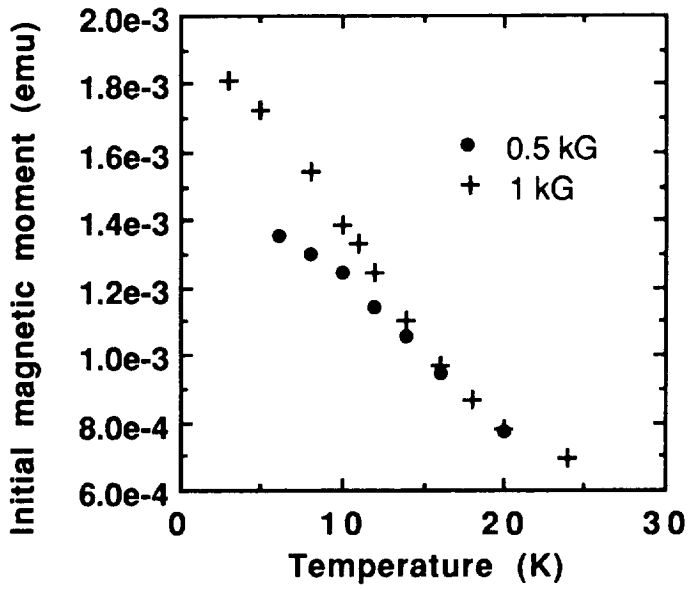

Fig. 1. Temperature dependence of the initial magnetization after a field of 1 kgauss (plus signs) and .5 kgauss (filled circles) was applied perpendicular to the substrate for ten minutes and then removed.

The average temperature-dependent pinning potential U(T) was estimated from the Anderson-Kim relation: $1/Mo(T)\ [\partial M(T,t)/\partial \ln(t)] = k_b T/U(T)$, where k_b is the Boltzmann constant and Mo(T) is the value of the initial magnetic moment at fixed temperature. The value of the pinning potential exhibited a nearly constant value of approximately 40 meV in the temperature range of 8 to 14 K. Above 14K, the pinning potential increased rapidly.

Fig. 2 shows the temperature dependence of the normalized decay rate $1/Mo[dM(T)/d\ln(t)]$ obtained at .5 kgauss and 1 kgauss. Both plots exhibit a pronounced peak and subsequent rapid drop. This behavior has been observed in bulk polycrystals of $YBa_2Cu_3O_7$ [6] after field cooling in 500 gauss. The temperature at which the maximum normalized rate occurs is observed to shift from 14K to 12K as the field is increased from .5 kgauss to 1 kgauss. While there is a qualitative similarity to the YBCO result, it should be noted that the temperature at which the maximum normalized rate occurs is roughly 15K lower in the Bi film than in the YBCO sample for the same applied field.

Recently, several theoretical models within the framework of thermally activated flux creep have been proposed to explain the origin of the peak in the temperature dependence of the normalized rate. In one such model[7], based on a theory of the elastic moduli of the vortex lattice, the pinning potential is related to critical current (Jc), the effective radius of pinning (d) and the average volume of flux bundles (V_b). This model, however, was not able to simultaneously reproduce the structure and position of the peak for the data presented here. Another model [8] involving a distribution of activation energies $\rho(U_o)$ has also been proposed. Relaxation results similar to ours have been reported for thin films of $ErBa_2Cu_3O_{7-\delta}$ and have been analyzed using the energy distribution model.[9] The distribution function obtained from an inversion of that data yields a peak in the distribution function at roughly 40 meV. This is similar to our estimated value of the pinning potential in the temperature range of 8-14K.

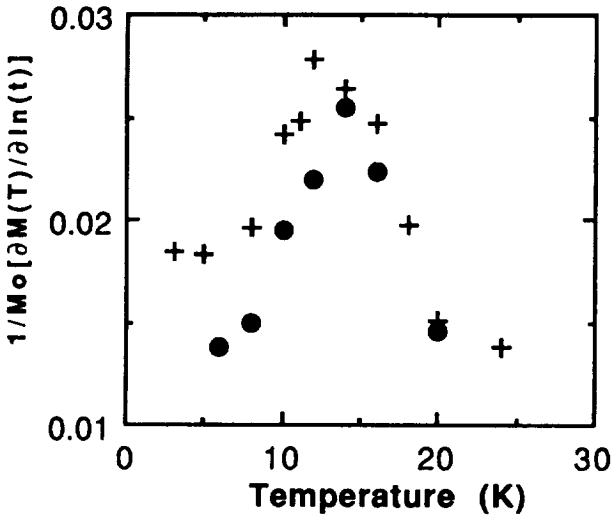

Fig. 2. Temperature dependence of the normalized relaxation rate 1/Mo(dM(T)/d(lnt)) after a field of 1 kgauss (plus signs) and .5 kgauss (filled circles) was applied perpendicular to the c-axis of the film for ten minutes and then removed.

Summary and conclusions

We have observed logarithmic decay of remnant magnetization in thin films of the high Tc phase in the Bi superconducting system and we report the first observation in this material of a peak in the temperature dependence of the normalized rate. The peak was found at a lower temperature and was sharper than that of YBCO for relaxation measured from the same field. Of the present theoretical attempts to explain the origin of the peak, we find the model of a distribution of activation energies most satisfactory.

It should be noted that a peak has not yet been observed in either Sr-La-Cu-O or Ba-La-Cu-O[10] at least for temperature less than 10 K. Therefore, further investigation is required in order to determine whether such a peak is a general feature of high Tc cuprate materials or is particular to those having several Cu-O planes in a unit cell.

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