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MAGNETIC RELAXATION IN THE 110 K SUPERCONDUCTING PHASE in Bi-Sr-Ca-Cu-O THIN FILMS

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Abstract

We have investigated the time dependence of remnant moment decay in a highly oriented, nearly single high Tc phase Bi-Sr-Ca-Cu-O thin film. A strictly logarithmic time dependence was observed over a 20 K temperature range for observation intervals of 2000 seconds. The normalized decay rate exhibits a peak around 14 K and has a relatively weak magnetic field dependence. These data are then compared with existing data on the YBCO and Eu - based superconductors.

Introduction

Unusually large thermally activated flux creep in a single crystal of $YBa_2Cu_3O_7$ (YBCO)[1] as well as a reported peak in the temperature dependence of the normalized relaxation rate[2] has prompted investigation into the time dependence of remnant magnetization in that system and in other high Tc superconductors[3,4,5]. However, the high Tc phase of the Bi-based material, especially in thin film form, has gone largely uninvestigated. We report here the results of magnetic relaxation experiments on highly oriented, polycrystalline films of the high Tc phase of Bi-(Pb)-Sr-Ca-Cu-O (BSCCO).

Sample fabrication

The BSCCO film was fabricated by rf magnetron sputtering onto single crystal MgO. A composite target with composition $Bi_{3.00}Sr_{1.90}Ca_{2.00}Cu_{3.00}$ was used. In addition, a PbO target and a CuO target were used to dope Pb in desired amounts and to optimize the Cu composition. Details of the sample synthesis are reported elsewhere[6]. The post-anneal composition was $Bi_{1.94}Pb_{0.08}Sr_{2.00}Ca_{2.04}Cu_{3.30}O_x$. The film used for this study exhibited zero resistance at 106.2 K and was c-axis oriented, nearly single phase, high Tc material as determined by X-ray diffraction.

Procedure

The magnetic measurements were performed by weak-field (approximately 2 Oe) cooling the sample from room temperature in a squid magnetometer. A magnetic field was applied for ten minutes parallel to the c-axis and then removed. The time decay of the remnant moment was measured at several temperatures and at fields of 0.5 kOe and 1 kOe.

Results and discussion

The decay was observed to obey a strictly logarithmic time dependence during observation intervals of 2000 seconds as shown in Figure 1. The normalized decay rate R and average pinning potential Uo were calculated from the Anderson-Kim model[7] using the relations:

$$M(t) = M_o\{1 - \frac{k_bT}{U_o}\ln(\frac{t}{\tau})\} \qquad \text{(Eqn. 1)}$$

and

$$\mathcal{R} = \frac{1}{M_0}\frac{\partial M(t)}{\partial(\ln(t))} = \frac{k_bT}{U_o} \qquad \text{(Eqn. 2)}$$

and a linear least squares fit to the data. The value of Mo was defined as the t = 1 second extrapolation of the linear fit. As single crystals of the high Tc phase have not yet been synthesized, the question of whether Uo represents a parameter intrinsic to the high Tc phase or is dominated by grain boundary structure remains an open one.

The temperature dependence of the normalized decay rate obtained at 0.5 kOe and 1 kOe is shown in Fig. 2. A sharp peak followed by a rapid drop is a qualitative feature of both sets of data. This phenomena has been reported in bulk polycrystals of YBCO[2] after field cooling in 0.5 kOe. A weak field dependence of peak position is also observed. The temperature at which the maximum normalized rate occurs shifts from 14K to 12 K as the field is increased from .5 kOe to 1 kOe. There are notable differences between these results and those reported for YBCO material. The peak is much more broad in the YBCO material than in the Bi-film and the temperature at which the maximum normalized rate occurs is roughly 15 K lower in the Bi film than in the YBCO sample for the same applied field.

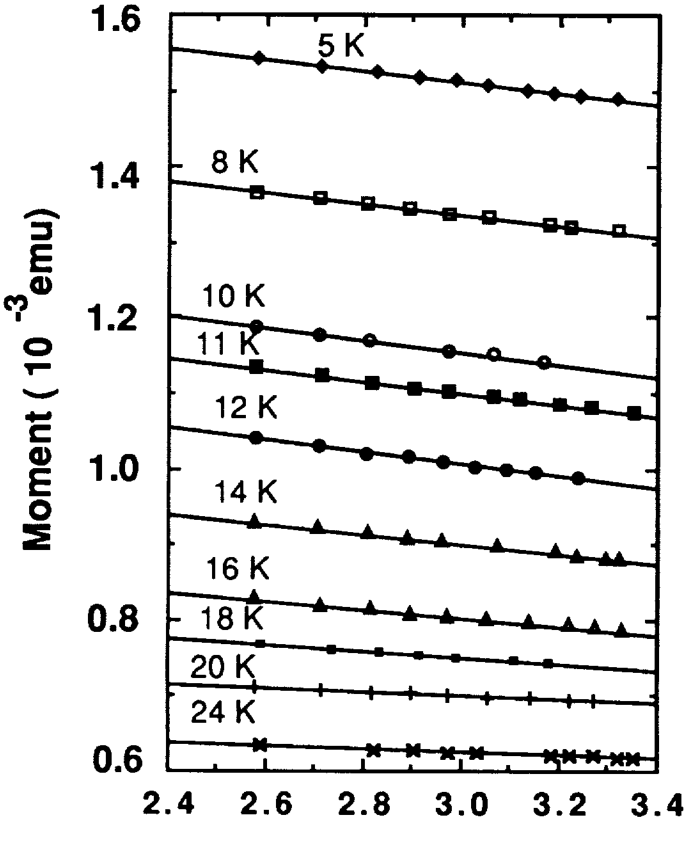

Fig.1. Time dependence of the remnant magnetic moment after a ten-minute application of a 1 kOe field parallel to the film's c-axis. The lines represent a least squares fit.

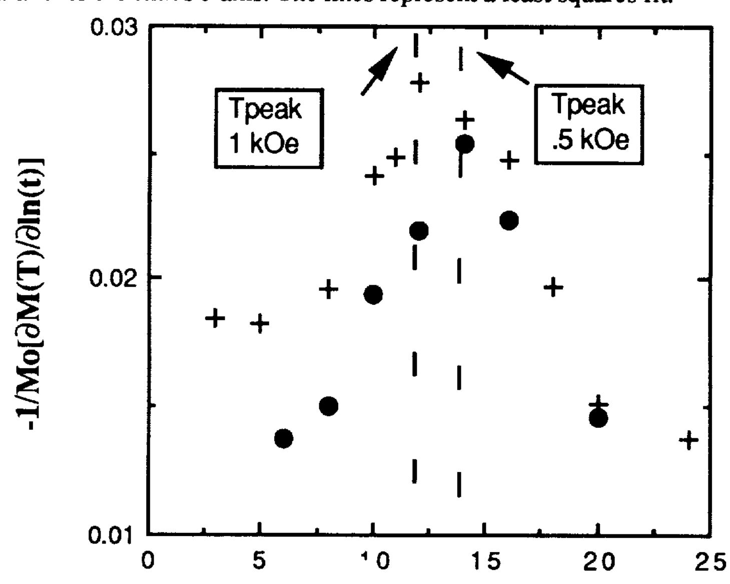

Fig. 2. Temperature dependence of the normalized relaxation rate of a highly c-axis oriented BSCCO thin film. The plus signs and filled circles indicate relaxation measured from applied fields of 1 kOe and .5 kOe respectively.

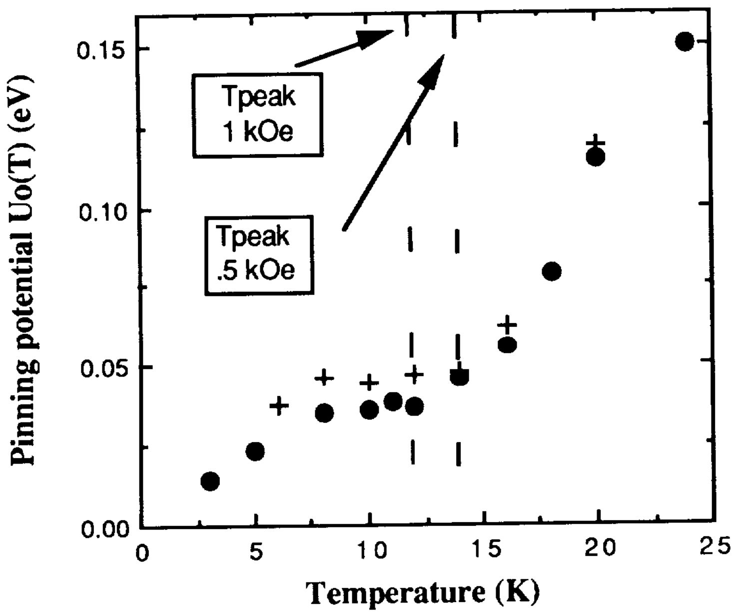

Fig. 3. Temperature dependence of the pinning potential Uo(T). The plus signs and filled circles indicate relaxation measured from applied fields of 1 kOe and .5 kOe respectively.

The temperature dependence of Uo is shown in Fig. 3. It is observed that the pinning potential had a nearly constant value of 40 meV between 8 K and 14 K regardless of the field from which relaxation was measured. The average pinning potential at 10 K was approximately 40 meV. It should be noted that at temperatures above T_{peak}, the pinning potential monotonically increases with temperature. This apparent inconsistency with the Anderson-Kim model of thermally activated flux creep makes the validity of the model, and hence the definition of Uo, questionable above T_{peak}.

Several theoretical models have been proposed in an attempt to explain the origin of the peak in the temperature dependence of the normalized rate. In one such model[8], based on a theory of the elastic moduli of the vortex lattice, the pinning potential is related to temperature-dependent critical current, effective radius of pinning and the average volume of flux bundles. Using this model the expression arrived at for the temperature dependence of the normalized rate is

$$\mathfrak{R} = \text{const.} \times \left[1 - \frac{T}{T_c(B_e)}\right]^{\frac{n(B_e)}{2} - 1} \left[1 + \left(\frac{T}{T_c(B_e)}\right)^2\right]^{-2} \qquad \text{(Eqn.3)}$$

where Be is the external flux density and n(Be) can be determined from critical current measurements. We used n(Be) as an adjustable parameter but were not able to simultaneously reproduce the qualitative structure of the peak for any reasonable choice of n(Be) using this model. It is possible that this model may be satisfactory for a very rigid lattice and that the fields used in this investigation were not sufficiently strong to generate a vortex structure for which Eqn. 1. is applicable.

Another model [9] involving a distribution of activation energies ρ(Uo) has also been proposed and has been used to analyze relaxation results similar to ours for thin films of $ErBa_2Cu_3O_{7-d}$[10]. For the Eu-based films, the pinning energy distribution function obtained from an inversion of that data exhibits a peak at roughly 40 meV. This is similar to the estimated average value of the pinning potential for our sample in the range of 8 - 14 K, suggestive of certain underlying similarities in the pinning mechanisms between the two materials. This model is based on the idea that as temperature is increased, low energy pinning sites become increasingly less effective until only very high energy pinning centers can pin vortices. The weak but observed magnetic field dependence of the peak position, however, is not explicitly included in the energy distribution model.

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 occurred at a lower temperature and was sharper than that of YBCO for relaxation measured from the same field. The average pinning potential of the sample was the same as that calculated for Eu-based superconducting films. Of the present theoretical attempts to explain the origin of the peak and the relevant energy scales for pinning, we find the model of a distribution of activation energies most satisfactory.

References

[1]Y. Yeshurun and A.P. Malozemoff, "Giant flux creep and irreversibility in an Y-Ba-Cu-O crystal: An alternative to the superconducting-glass model", Phys. Rev. Lett. **60** (1988) 2202.

[2]M. Tuominen, A.M.Goldman, M.L.Mecartney, "Time-dependent magnetization of a superconducting glass",Phys. Rev B 37, 548 (1988).

[3]T. Kotani, K. Ohkura H. Takei, and T Tada,"Magnetic properties of Bi- and Tl -based single crystals", To appear in Proceedings of ISS 1989.

[4]S. Hatta, Y. Ichikawa, H. Adachi, and K. Wasa:, "Magnetic aftereffects in high Tc superconducting thin films", Japn J. Appl. Phys. 28 (1989) L 422-423.

[5]H. Kumakura, K. Togano, E. Yanagisawa, K. Takahashi, M. Nakao, H. Maeda, Magnetic relaxation in high-Tc oxide superconductors", Japn. J. Appl. Phys **28** (1989) L 24-26.

[6]A.Tanaka, N. Kamehara and K.Niwa,"Composition dependence of high Tc phase formation in Pb-doped Bi-Sr-Ca-Cu-O thin films""Appl. Phys. Lett. **55**, 1252 (1989).

[7]P. W. Anderson, "Theory of flux creep in hard superconductors",Phys. Rev. Lett. **9**, 309 (1962).

[8]T. Fujiyoshi, K. Toko, T. Matsushita, and K. Yamafuji, "Temperature dependence of flux creep in high Tc superconductors", Jpn. J. Appl. Phys. **28** (1989) L 1906-1908.

[9]C. W. Hagen and R. Griessen, "Thermally avtivated magnetic relaxation in high Tc superconductotrs", Studies of high temperature superconductors, Nova Science Publishers Inc.

[10]H. Furukawa, K. Kawaguchi, and M. Nakao, "Distribution of flux pinning energies in superconducting thin films", To appear in Proceedings of ISS 1989.