

Low field relaxation measurements of induced magnetic moment in Bi(2223)/Ag tape and Bi(2212) single crystal

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Abstract. Relaxation of the induced magnetic moment and of the associated critical current was studied in detail at low external fields on a Bi(2223)/Ag tape and a Bi(2212) single crystal. In the low-field range, both samples exhibited a large variation of the relaxation rate $R = -d|m|/d \ln t$ and the normalized relaxation rate $S = -d \ln |m|/d \ln t$. The maxima of the $R(B_c)$ and $S(B_c)$ dependencies are correlated with the shape of the magnetic hysteresis loop. Above 0.5 T, two relaxation regimes were recognized. The crossover from the fast to the slow relaxation regime is discussed.

1. Introduction

The Bi-based superconducting tapes represent the most perspective material for technical applications. One of the important characteristics is the relaxation behavior. Due to the low effective activation energy, a significant role of surface effects, and the inhomogeneous local field distribution at low external fields, study of the dissipative mechanisms in the Bi-based superconductors is a rather complex task. In granular samples like the Ag-sheathed Bi(2223)/Ag tapes the situation is further complicated by presence of the intra- and intergranular currents. To be able to consider effects of the intergranular currents on the total relaxation behavior of the studied Bi(2223)/Ag tape, the relaxation in a Bi(2212) single crystal was also investigated. The aim of this paper is to describe quantitatively relaxation measurements at low fields and to find some correlation between relaxation characteristics of both samples.

2. Experiment and Discussion

The monofilamentary Ag-sheathed tape of $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ [Bi(2223)/Ag with dimensions of $5 \times 2.8 \times 0.032 \text{ mm}^3$ and the $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ single crystal [Bi(2212)] with dimensions of $2.6 \times 1.1 \times 0.035 \text{ mm}^3$ were investigated for this paper. The tape was prepared by the standard powder-in-tube method followed by rolling, the crystal was grown using a directional solidification method employing the stationary crucible in a strong temperature gradient [1].

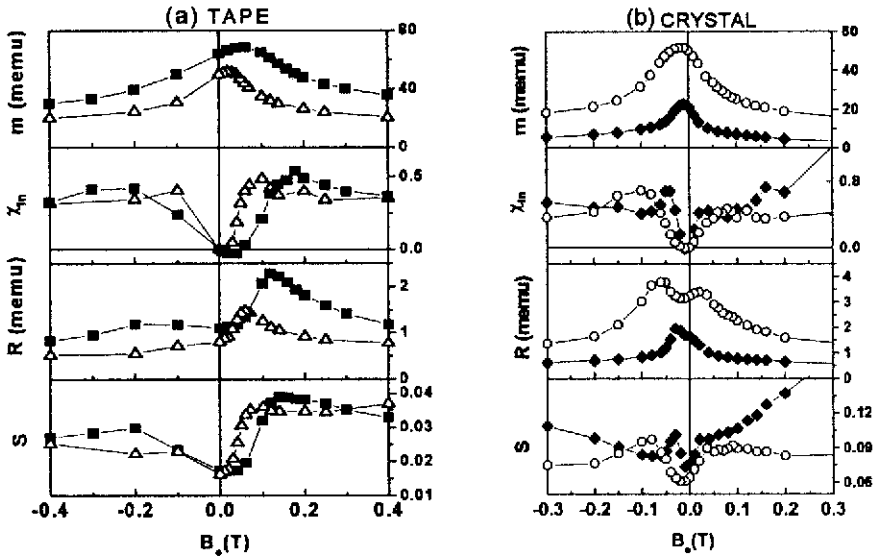


Figure 1. Comparison of the field dependencies of magnetic moment m , logarithmic susceptibility χ_{ln} , relaxation rate $R = -d|m|/d\ln t$ and normalized relaxation rate $S = -d\ln|m|/d\ln t$ for (a) Bi(2223)/Ag tape at 10 K (squares) and 20 K (triangles), and (b) Bi(2212) single crystal at 10 K (circles) and at 15 K (diamonds)

Magnetic hysteresis loops (MHL) and conventional relaxation of the induced magnetic moment at a constant magnetic field were measured by means of a QD SQUID magnetometer. To ensure the full critical state of the vortex system, the target field was reached from a large field ($|B_e| \geq 3T$). The applied field was always perpendicular to the sample plane. Conventional relaxation was measured at different fields, each for 1000 seconds after the field stop. To establish shift t_0 of the time scale origin, the experimental $m(\ln t)$ dependencies were fitted by the simple logarithmic function $A + B \ln(t + t_0)$. After the time correction for t_0 , the relaxation rate $R = -d|m|/d\ln t$ and the normalised relaxation rate $S = -d\ln|m|/d\ln t$ were evaluated.

In Fig. 1(a) the field dependencies of the magnetic moment m , the logarithmic susceptibility $\chi_{ln} = d\ln|m|/d\ln|B_e|$, R , and S are compared for Bi(2223)/Ag at 10 K and 20 K. In Fig. 1(b) the comparison is also made for a Bi(2212) single crystal at 10 K and 15 K. Similar peaks appear at low fields on the $R(B_e)$, $S(B_e)$, and $\chi_{ln}(B_e)$ dependencies in both samples. For the Bi(2223)/Ag tape at 10 K, there is always a big peak lying at a positive (descending) field and a smaller peak positioned at a negative (ascending) field. For the Bi(2212) single crystal at 10 K the situation is just opposite: the bigger peaks lie at negative fields while the smaller ones occur at positive fields. With increasing temperature the big peaks shift towards $B_e = 0$ while the smaller ones almost disappear. Only one, central maximum is observed on the $m(B_e)$ dependence. It appears for the Bi(2223)/Ag tape at a positive field, for the Bi(2212) single crystal at a negative field. With increasing temperature, the maximum shifts towards $B_e = 0$ for both samples.

The significant feature of the maxims of the $\chi_{ln}(B_e)$, $S(B_e)$, and $R(B_e)$ dependencies is that, for the given sample, they consistently shift with temperature. This indicates that the shapes of $R(B_e)$, $S(B_e)$, and $\chi_{ln}(B_e)$ dependencies are correlated. Perkins et al. [2] found from the scaling properties that in $\text{TmBa}_2\text{Cu}_3\text{O}_7$ single crystal S is a linear function of χ_{ln} at high

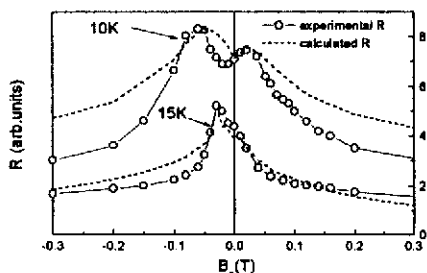


Figure 2. The field dependence of the relaxation rate R for Bi(2212) crystal at 10 K and 15 K. The experimental data are plotted as circles, the $R(B_c)$ curves calculated from Eq. (1) are shown as dashed lines.

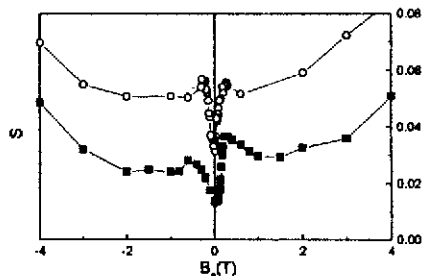


Figure 3. The field dependence of normalized relaxation rate S for Bi(2223)/Ag tape (squares) and Bi(2212) single crystal (circles), both at $T=5$ K

fields and temperatures. Our experiments show that this relationship holds also at low fields.

To describe the relaxation process at low fields, we used the equation of motion deduced with taking into account the backward jumps of vortices [3,4]. For a slab magnetized in the plane one obtains

$$dj/d\ln t = \frac{B_c \sinh(\sigma j/j_c) + \mu_0 l j \cosh(\sigma j/j_c)}{(B_c \sigma/j_c + \mu_0 l) \cosh(\sigma j/j_c) + \mu_0 l j \sigma/j_c \sinh(\sigma j/j_c)} \quad (1)$$

where j is the current density, $j = -m/(a^2bc)$, (a, b, c) are dimensions of the sample, $2l$ is the distance between two adjacent pinning sites, and $\sigma = U_0/kT$. The simplest, Kim-Anderson, form of the $U(j)$ dependence is assumed, $U = U_0(1 - j/j_c)$, with field independent j_c and U_0 . Even though this simple model does not take into account the stray field effects that are important at low fields [2,5,6], it describes surprisingly well the experimentally observed relaxation processes at low fields. This is documented by the fit of the experimental $R(B_c)$ curves for the single crystal at 10 K and 15 K as shown in Fig. 2. The calculated curves have two maxims similar to the experimental ones.

The dramatic change of the normalized relaxation rate S with field in the low field region (0-1.5 T for the tape and 0-0.5 T for the crystal) (see Figs. 1 and 3) seems to be just due to normalization to m . It is a strong function of field in this region which reflects in the shape of the $S(B_c)$ dependence. The strong field dependence of m and consequently also of S at fields below the penetration field, B_p , has been also attributed to the self-field effects [2,5,6]. In the intermediate field range, S changes more gradually and develops a shallow minimum. Such a behavior has been also observed in other types of high- T_c specimens [6]. The high-field part of $S(B_c)$ rises steeply and tends towards $S=1$ at B_{in} (irreversible field).

During relaxation measurements in the Bi(2223)/Ag tape we observed a clear crossover between two relaxation regimes on the $m(\ln t)$ curve (see Fig. 4). The similar crossover has been also observed in BSCCO [7] and YBCO [8] single crystals and was ascribed to transition from surface to bulk pinning [9]. Paasi et al [10] attributed the abrupt change in the $m(\ln t)$ slope observed in a Bi(2223)/Ag tape at low fields to the transition from a fast intergranular to a slow intragranular current relaxation.

Bending of granular Bi-based tapes into a small radius was proposed as a method how separate effects of inter- and intragranular currents [11]. After bending, the intergranular currents are believed to vanish while the intragranular ones to be only slightly affected. In order to study the role of the intergranular currents in the relaxation process, we bent the

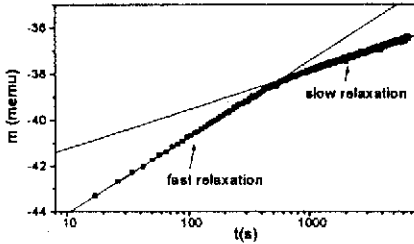


Figure 4. Observed crossover between two regimes of the magnetic moment relaxation at $T=5$ K and $B=3$ T

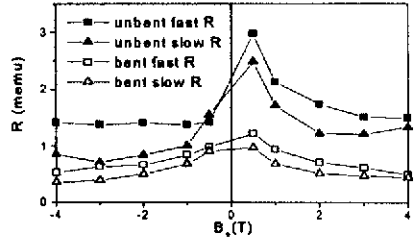


Figure 5. Field dependence of relaxation rate R for two relaxation regimes: fast and slow for the unbent and bent Bi(2223)/Ag tape at $T=5$ K.

Bi(2223)/Ag sample into a small radius [12]. The field dependence of the relaxation rate R is presented in Figure 5 for the slow and fast relaxation regime before and after the bending. It is clearly seen that the bending significantly reduces asymmetry of $R(B_c)$. The other important feature is the reduction of the difference between R for the slow and fast relaxation.

3. Conclusions

We studied the low field relaxation processes in a Bi(2223)/Ag tape and a Bi(2212) single crystal. A strong correlation between the relaxation rate $R = -d|m|/dln t$, the normalized relaxation rate $S = -d \ln|m|/d \ln t$, and the logarithmic susceptibility $\chi_{ln} = d \ln|m|/d \ln|B_c|$ was found. The shape of the $R(B_c)$ dependence is qualitatively described by means of the flux-creep equation derived for a slab magnetized along the plane, taking into account the backward jumps of vortices and field-independent U_0 and j_c . The crossover observed on the $m(\ln t)$ dependence in the Bi(2223)/Ag tape might indicate two time windows at which different current contributions dominate the relaxation process.

Acknowledgements

This work was supported by GA AVČR under the contract A1010512.

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