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INVESTIGATION OF CURRENT TRANSPORT NORMAL AND PARALLEL TO THE TAPE PLANE IN BSCCO/AG TAPES

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ABSTRACT

We have performed transport, resistivity and critical current measurements on Bi-2223/Ag and Bi-2212/Ag tapes with current directions both parallel and perpendicular to the tape plane in magnetic fields up to 7 T and $50<T<250$ K. We find that the resistivity along the tape normal (nominal c-axis in a textured tape) is metallic, scales with the in-plane resistivity at all fields and is dramatically reduced from single crystal c-axis values. Similarly, the critical current along the tape normal exhibits magnetic field and field orientation dependences similar to those for current flow along the tape plane. These results indicate that current flow along CuO_2 planes dominates current transport even along the tape normal in highly textured tapes.

INTRODUCTION

The impressive performance of Bi-2212 and Bi-2223 high temperature superconductors, HTS, prepared by the oxide-powder-in-tube, OPIT, process indicates that limitations to high critical current density, J_c, caused by weak intergranular coupling can be reduced to acceptable levels. Even so, J_c's in the best OPIT tapes are 1-2 orders of magnitude below those achieved in single crystal thin films, indicating that weak links are still a limiting factor. Correlations between high J_c and a high degree of c-axis texture, combined with a plate-like morphology, have suggested models such as the "brickwall" [1], which envisions intergranular current transfer across large area c-axis twist boundaries as a means of avoiding weak links associated with large-angle tilt boundaries. The transfer of large current densities along crystallographic c axes is however inhibited by the high degree of crystalline anisotropy possessed by the bismuth-based HTS compounds. This anisotropy is manifested in Bi-2212 single crystals by a resistivity ratio $\rho_c/\rho_{ab} \sim 10^5$ near T_c and by a c-axis resistivity that rises with decreasing temperature(semiconducting-like) until a coupling transition occurs and ρ_c drops to zero. This coupling transition is depressed to temperatures far below T_c by a magnetic field applied along the c-axis [2], [3]. In addition, the c-axis critical current density $J_{c,c}$ is 3-4 orders of magnitude smaller than $J_{c,ab}$ [3], [4]. Recent information from sample sectioning measurements [5], from magneto-optic studies of flux penetration profiles [6] and from microstructural studies [7] suggest a different picture. The presence of highly textured layers near the Ag interface that are strongly linked and that sustain high current densities seems now to be well established. The central core region by contrast is considerably less well textured and contains regions that allow flux penetration normal to the tape plane. Current flow in the thin interface region presumably occurs through a percolative path of low-angle tilt boundaries that facilitate transfer along ab planes without requiring substantial c-axis transport.

A question remains as to the nature of the strong current paths and the grain boundaries that permit the high current densities that have been achieved in these BSCCO/Ag tape conductors. The purpose of this investigation is to measure the resistivity and critical current of BSCCO/Ag tapes for transport normal to the tape plane, which is along the nominal c-axis. In a brickwall structure, this geometry would force current to flow along crystallographic c axes and should result in a semiconducting behavior for the resistivity and a strong reduction in the critical current density. We have studied the dependence of resistivity and critical current on temperature, magnetic field and field orientation to determine the factors limiting current flow across the thickness of the tape and to look for characteristics of c-axis conduction. Preliminary results of this study were reported [8].

EXPERIMENTAL

We performed transport measurements on several samples of Bi2223/Ag tape and on two samples of Bi2212/Ag tape. To measure the resistivity ρ_r along the rolling plane (close to the nominal crystallographic ab plane) we used the HTS cores of tapes from which the Ag sheath had been mechanically removed. These bare cores were also used with a "transformer" lead configuration. Standard four-lead and "transformer" lead [9] configurations were attached with Ag paste and cured at 300^o C. For ρ_n, resistivity parallel to the tape normal (nominal c-axis direction) and for the critical current (I_c) measurements along the tape normal, we removed the Ag from the sides of the tapes to ensure a uniform current density. Current and voltage contacts were applied to the intact Ag sheath segments on the flat tape surfaces, utilizing the good ohmic contact with the BSCCO core surfaces. We also measured the dependence of I_c on magnetic field orientation for this current direction.

RESULTS

Figure 1 shows ρ_r and ρ_n versus temperature for five different Bi2223 tape samples with critical currents ranging from ~ 15 to 31 A (J_c's of ~ 1.2 - 2.4 x 10^4 A/cm^2) at 75 K in self field. The inset defines the rolling, normal and transverse directions (r, n, and t respectively). As seen in the figure, the resistivity ratio ρ_n/ρ_r at 300 K is ~ 4 - 10, in marked contrast to the values 10^4 - 10^5 for ρ_c/ρ_{ab} seen typically in Bi-2212 single crystals. In addition ρ_n(T) shows metallic behavior and there is no sign of the semiconducting dependence characteristic of ρ_c (T) in single crystals. The magnitude of ρ_r near T_c is of order 1 mΩ, about ten times larger than single crystal values. The data also shows an inverse correlation between ρ_r and J_c, i.e., the samples with the lowest values of the normal state resistivity in the rolling plane exhibit the highest values of critical current density. This indicates that ρ_r provides a diagnostic for intergranular connectivity. Similar results were obtained on tape samples of Bi2212. Resistivity

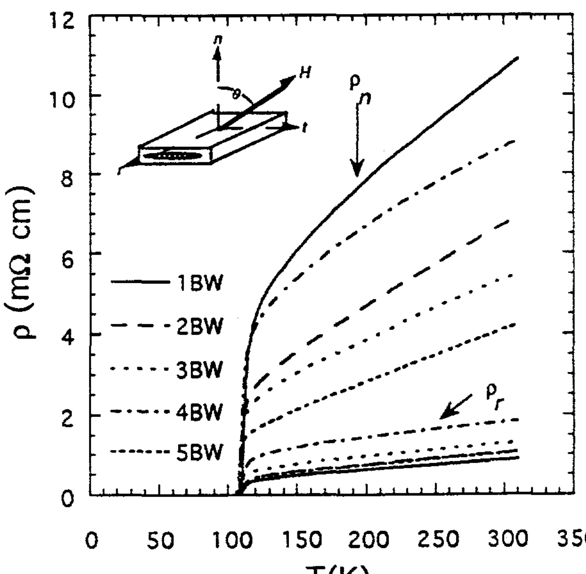

Fig. 1. Resistivities ρ_n for current direction along the tape normal and ρ_r for current along the rolling plane versus temperature for 5 Bi2223 tapes.

measurements were also taken on Bi2212 tape samples in magnetic fields of 0 - 7 T applied normal to the tape plane for the current directions: I || r and I || n. The broadening of the transition typical for I || ab in single crystals for this field orientation is seen for both current directions. This is in contrast to the I || c characteristic for single crystals where magnetic fields along the c direction extend the semiconducting behavior to lower temperatures. As we previously reported [8], the broadening of the transition for H || r is much reduced for tape samples. The similarity of ρ(T,B) for both current directions suggests a common physical origin for the observed field induced dissipation, which appears to be intragranular ab-plane vortex motion.

This is illustrated more clearly in Figure 2, where we show sets of ρ(T) normalized by ρ(140K) to show superposition for several different combinations of field and current orientations. In figures 2a and 2b, we see that ρ(T)/ρ(140) for H || n at 1T is nearly identical to that for H || r at 7T for both current directions. There is substantial evidence from single crystal and from tape measurements that intragranular dissipation is primarily a function of the component of the magnetic field along the c-axis. Thus the resistivity for H || r is coming mainly from the average granular misalignment with respect to the tape plane. As a result, from the scaling shown in Fig. 2a, we can deduce the average misalignment angle of the tape as $\tan \phi_c = 1/7$, i.e. $\phi_c = 8^o$. This is a reasonable value and agrees with estimates of texture obtained by x-ray pole figure analysis on these tapes. It is surprising that this same scaling and thus estimate of misalignment is seen for I || n in Fig. 2b. This implies that the current pathways followed for flow along or normal to the tape plane are similar and primarily involve transport along grains that are inclined by a small angle with respect to the plane. This point is further corroborated in Fig. 2c, which shows scaling of the resistivity for the two current directions at the same value 3 T of the magnetic field, H || n. This is consistent with a picture in which the average c-axis component of the field for current pathways along or normal to the plane is the same.

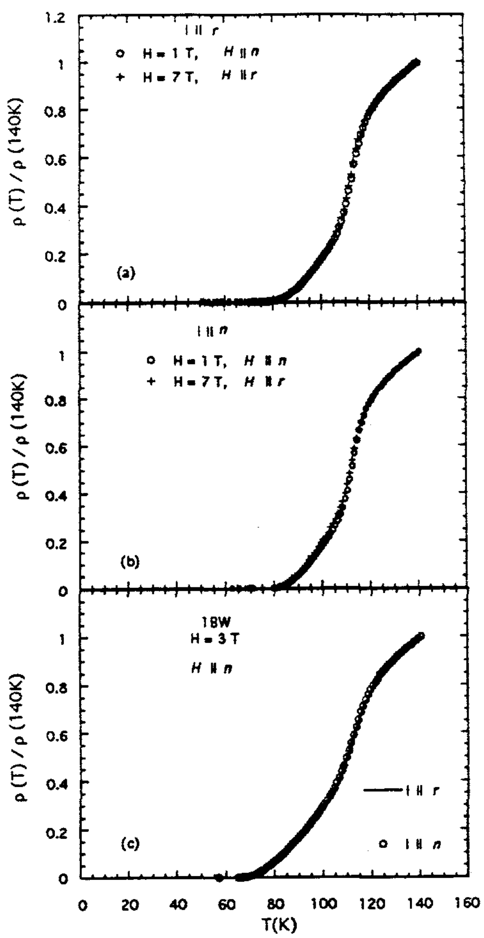

Fig. 2 Resistivity versus temperature plots, normalized by the resistivity at 140 K for Bi2223 tapes showing superposition for certain pairs of field and current orientations as specified in the plot labels.

We previously have reported[8] critical current versus magnetic field orientation with respect to the tape plane for the two current directions. An important feature is that the angular dependencies of the critical currents for both directions are quite similar, both showing a strong peak when the field is parallel to the tape surface. The scaling of the critical current with the normal component of the magnetic field H cos θ is also good with some deviation due to imperfect texture near H || r [8]. The deviation from scaling for both I || r and I || n are also very similar, thus confirming the existence of superconducting current paths primarily along tilted ab planes even for I ||n. Irrespective of the value of I_c, we observe similar results for the five tapes. Since the critical current for I || n is too large to be accounted for by Josephson-current limited transport, as shown by Hensel et al.[9], the transport supercurrent does not likely reflect this c-axis transport and intergrain transfer mechanism. In addition, from the scaling of the magnetic field dependence of the critical currents for I || r and I ||n, we obtained a similar order of misalignment ~ 9-11^o for the five tapes. We also conducted measurements in the " transformer" configuration in which current contacts are applied to the top of the tape and voltages are measured across the top and bottom surfaces. We found V_{top}/V_{bot} ratios of order one[8] in contrast to measurements on single crystals.

SUMMARY

We performed four different types of measurement to identify the nature of the superconducting current path in Bi2223 and in Bi2212 tape samples.: (1) resistivity anisotropy from currents applied along and perpendicular to the tape plane; (2) dependence of the critical current on field angle for the two different current directions; (3) resistivity anisotropy using the "transformer" lead configuration; and (4) critical current measurements using the "transformer" configuration . From these measurements we deduce the following: (1) the resistivity anisotropy in the tapes is of order 10, which is several orders of magnitude smaller than that characteristic of Bi2212 single crystals; and (2) the supercurrent path for transport along and perpendicular to the rolling plane is similar, with the dissipation coming primarily from flow along the intragranular CuO_2 planes. Thus any c-axis transport present in these tapes is not a limitation within the strongly connected pathways and is not reflected in the temperature and field dependence of the transport properties. These results are consistent with a picture in which intergranular currents flow primarily between ab planes joined by small misalignment angles.

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