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Intragranular and intergranular behaviour of multifilamentary Bi-2223/Ag tapes

J.-F. Fagnard [a,b], Ph. Vanderbemden [a], D. Crate [a], V. Misson [a,b], M. Ausloos [b], R. Cloots [c]

[a] *Montefiore Electricity Institute, SUPRAS, University of Liège, Sart-Tilman B28, B-4000 Liège, Belgium*
[b] *Physics Institute, SUPRAS, University of Liège, Sart-Tilman B5, B-4000 Liège, Belgium*
[c] *Chemistry Institute, SUPRAS, University of Liège, Sart-Tilman B6, B-4000 Liège, Belgium*

Abstract

This communication aims at reporting the superconducting properties of Bi-2223/Ag tapes determined by using various measuring techniques. First, the original samples have been characterized by electrical resistance, AC susceptibility, and DC magnetization. The transport (intergranular) critical current vs. magnetic field was also determined at $T = 77$ K using pulsed currents up to 40 A. Next, the same combination of experiments was performed on bent tapes in order to bring out relevant information concerning the strength of the intergranular coupling. The results show that intergranular and intragranular currents differ by at least one order of magnitude. Finally, additional magnetic measurements were carried out in order to determine the anisotropy ratio J_c^{ab} / J_c^{c}, which was found to lie around 30.

Keywords: Critical current; magnetic measurements; multifilamentary tapes.

1. Introduction

In spite of promising current carrying properties over long distances, the major disadvantage of Bi-based materials is their low irreversibility field H_{irr}, which lies around 0.1 T at 77 K [1]. The direct consequence is a sharp decrease of the critical current density with the magnetic field at relatively 'high' temperatures ($T \sim 77$ K) [2,3]. An additional characteristic of Bi-2223 materials is their high anisotropy, leading to a severe dependence of the critical current density with respect to the magnetic field direction [4-7].

The aim of the present work is to investigate both the electrical and the magnetic properties of *multifilamentary* Bi-2223/Ag tapes with various measurement techniques including electrical resistivity, *I-V* curves, magnetization and AC susceptibility. Each technique brings out specific information on *intragranular* critical currents (J_{cG}) or *intergranular* critical currents (J_{cJ}), and their comparison is helpful in elucidating the current limitation processes in HTS tapes [8]. A particular emphasis will be placed on understanding the importance of connectivity and anisotropy of the critical currents through estimating the J_{cG}^{ab}/J_{cJ}^{ab} and J_{cJ}^{ab}/J_{cJ}^{c} ratios.

2. Experimental techniques

The multifilamentary Bi-2223/Ag tapes studied in this paper have been prepared with the power-in-tube technique [9] and are commercialised by Nordic Superconductor Technology (NST). The tapes are characterized by a T_c of 106 K and I_c (77 K, self-field) = 40 A.

The *I-V* characteristics were measured by the conventional four-points method, using a Quantum Design physical property measurement system (PPMS). A home-made pulsed-current set-up was used to perform high-J_c measurements up to 40 A. For all transport measurements, J_c was extracted using a 1 µV/cm threshold.

DC magnetic measurements at several temperatures and magnetic fields were performed in the PPMS using an extraction method allowing a typical resolution of 10^{-7} Am^2. AC magnetic susceptibility measurements were performed in a home-made susceptometer allowing the direction of parallel DC and AC magnetic fields to be rotated around the sample [10].

In order to estimate the relative importance of intergranular and intragranular magnetic moment contributions m_J and m_G, the grain boundaries were damaged by severely bending the tape up to a 1 mm radius, as proposed by Müller [11] to suppress the intergranular part of the response.

3. Results and discussion

3.1. Magnetic moment measurements

Fig. 1 shows the magnetic moment $m(H)$ curves measured at $T = 77$ K for $H||c$ on a tape sample before (open symbols) and after bending (solid symbols). The same measurements have been performed on this sample for $H||ab$. As expected [12], the magnetization of the latter is smaller than the magnetization of the virgin tape due

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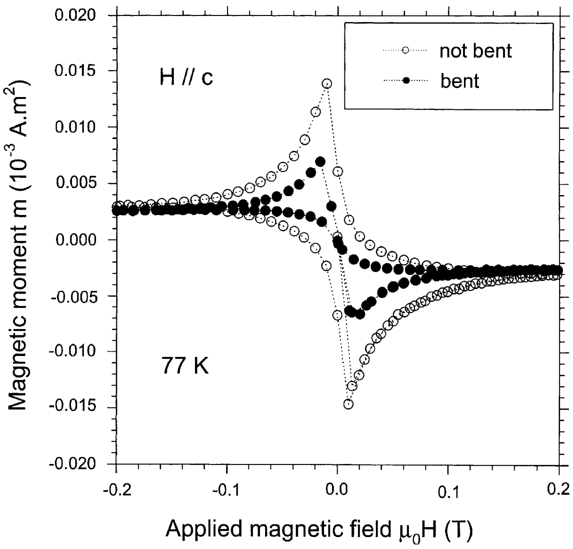
to the disappearance of the intergranular current contribution to the magnetic moment. Notice that the difference is not very large when $H||ab$: the bending mostly affects the links in the *ab*-plane. The overall magnetization is about one order of magnitude larger when $H||c$ compared to the measurement when $H||ab$. These measurements will be used below to obtain the connectivity ratio J_{cG}^{ab}/J_{cJ}^{ab}.

Fig. 1. *Magnetic moment of bent and intact tapes for an applied magnetic field parallel to c-axis at 77 K.*



3.2. Irreversibility line

First of all, it should be recalled that the 'true' irreversibility line (IL) is contained between the magnetic IL and the resistive IL. The magnetic IL is the field beyond which the difference between the hysteretic loop branches is below a non-zero threshold, i.e. a non-zero J_c, and thus located *below* the 'true' IL in the technological diagram *H-T*. On the other hand, the resistive irreversibility field is the field at which the resistance drops below a threshold (here, 1 μΩ) and is located just *above* the 'true' IL.

The data obtained by both experimental methods are summarized in Fig. 2. The magnetic measurement criterion is much more severe than the electrical method criterion. For the magnetic measurements, the electric field is roughly given by $E = 0.5\mu_0 \Lambda \mathrm{d}H/\mathrm{d}t$ where Λ is the current loop size.

The largest possible length is the average filament half-width of 100-150 μm. Thus the electric field upper bound is about 10^{-8} V/m, i.e. two or three orders of magnitude below the electric field criterion used in the transport method (3×10^{-6} V/m).

3.3. Intragranular and intergranular behaviours

The measurements performed on bent and intact tapes show the existence of two regimes as established by numerous authors [6,8,13]. For the intact tape, the low field J_c behaviour can be understood as an intergranular dissipation in the weak-links, leading to the power-like law typical in percolation. At high fields, the behaviour follows an exponential law suggesting a J_c degradation by flux motion inside the grains [2]. For the bent tape, the low field regime disappears because the intergranular current contribution has been suppressed.

In our case, at high fields, the characteristic decay field B_g of the exponential law has been measured to be the same for the bent and the intact tape at any temperature. This result strongly confirms that the high field behaviour is dominated by the intragranular component.

We have used the intergranular magnetic moment model developed by Brandt [14] to extract the intergranular critical current. By fitting the irreversible intergranular magnetic moment component with this model and by assuming a field dependent J_{cJ}^{ab}, we obtain, at 0.1 T, $J_{cJ}^{ab} = 1.04 \times 10^7$ A/m^2.

For the intragranular critical current, the Bean model can be used and gives $J_{cG}^{c} = 6.6 \times 10^7$ A/m^2 at 0.1 T. The J_{cG}^{ab}/J_{cJ}^{ab} ratio at 77 K and 0.1 T is thus evaluated to lie around 5-10. The ratio estimated by Müller et al. is about 100 [12].

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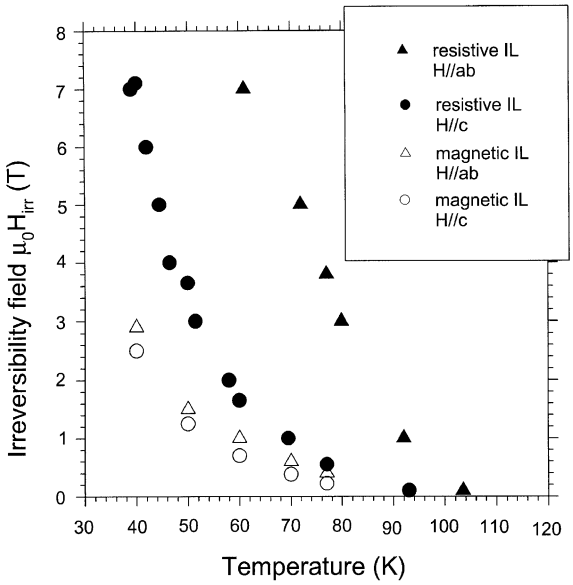
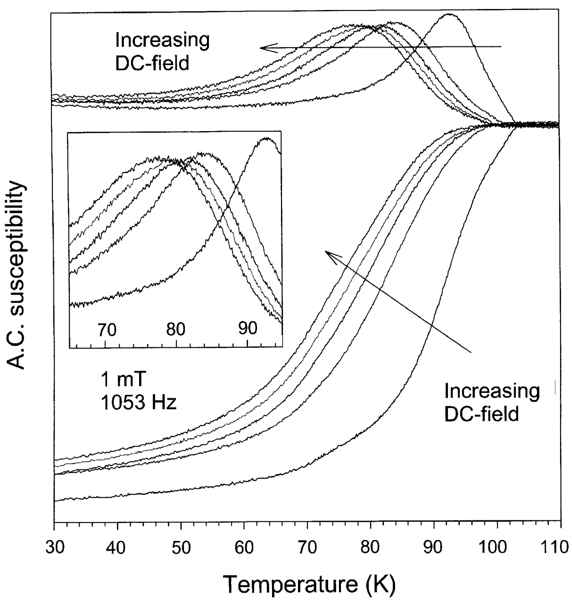
Fig. 2. *Resistive and magnetic irreversibility lines for an applied magnetic field parallel to c-axis and ab-plane.*



3.4. Alternative susceptibility

In an AC magnetic measurement, the tape response is usually given by a complex combination of superconducting shielding currents and eddy currents in the silver [15]. In the measurements discussed below, the eddy current signal was checked to be small with respect to the superconducting signal.

Fig. 3. *AC-susceptibility for different applied DC magnetic fields parallel to the filaments.*



The real and imaginary parts of the alternative susceptibility were measured in the presence of several DC fields added to the 1 mT AC measurement field (Fig. 3). For $H||ab$, the J_c determination requires to take J_c anisotropy into account. In the present case, by assuming a priori $J_{cJ}^{c} << J_{cJ}^{ab}$, the full penetration field at a given temperature only depends on J_{cJ}^{c} and geometric factors. At 77 K and 70 mT, the critical current along the c-axis was worked out to be 3.8 x 10^6 A/m^2. Transport measurements at the same applied field yield a J_{cJ}^{ab} value of 1.2 x 10^8 A/m^2. Thus we estimate the ratio J_{cJ}^{ab}/J_{cJ}^{c} to lie around 30. This value is well within the range measured in monocore tapes (10-50) [16,17] and much smaller than the intragranular anisotropy ratio (~1000) of the Bi-2223 phase.

4. Conclusions

Transport and magnetic measurements have pointed out the importance of the criterion for determining the irreversibility field. The irrevers-ibility field determined by transport method was seen to be higher for *H*||*ab*-planes than for *H*||*c*-axis by a factor around three while the irreversibility field determined magnetically is not very dependent of the magnetic field direction because the criterion is much more severe in this case.

Comparison between the magnetic moment measurements of bent and not bent tapes shows two different behaviours following the applied field amplitude. Finally, the connectivity ratio, J_{cG}^{ab}/J_{cJ}^{ab}, is around 40-50 and the anisotropy ratio, J_{cJ}^{ab}/J_{cJ}^{c}, has been shown to be 30 at 77 K and 0.1 T.

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