Magnetic and transport measurements on
melt-textured DyBCO single domains

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Abstract

In this communication we report critical current measurements of melt processed $DyBa_2Cu_3O_{7-x}$ samples determined by several measuring techniques. First the material was characterized by AC susceptibility and DC magnetization. The results are characteristic of good quality melt-processed (RE)BCO material with $T_c \approx 89$ K and $J_c(77$ K, 1 T$) \approx 10^4$ A/cm^2. Next, pulsed currents were used in order to determine both *I-V* curves and transport critical currents. The origin of the discrepancy between transport and magnetic data has been discussed. The results point out significant local variations of the critical current density throughout the single domain.

Keywords: Critical current ; magnetic measurements ; melt-textured (RE)BCO materials

1. Introduction

The micro structure of bulk melt-textured (RE) BCO materials (RE = Y, Nd, Dy, ...) consists of large grains, called *domains,* characterized by a high critical current density J_c as well as a large irreversibility field H_{irr} at $T = 77$ K [1-6]. Therefore these materials are promising candidates for various engineering applications [7,8]. The two main parameters relevant to applications—H_{irr} and J_c—can be determined either by *transport* (direct) or *magnetic* (indirect) measurements. The comparison of the results obtained by both methods on DyBCO single domains is the purpose of the present work.

2. Experimental techniques

Melt-textured DyBCO specimens were prepared in the S.U.P.R.A.S. group using a top seeding technique. The details of the synthesis process as well as specific growth features have been described in a previous paper [9]. The single domains have a typical size of 3 cm diameter. In order to investigate the distribution of the properties, a single domain was first cut into 9 cubic samples which were shown to be characterized by a critical temperature T_c in the range 89.1-89.5 K. Then some of these samples were cut into thin bar shaped samples. These specimens were used for both transport and magnetic measurements.

DC magnetic moment measurements were performed in a Quantum Design physical property measurement system (PPMS) using an extraction method. AC magnetic susceptibility measurements were performed in a home-made susceptometer [10].

In view of transport measurements, ohmic contacts were made by depositing DuPont 6838 silver epoxy paste annealed in flowing O_2 for 15 min. $R(T)$ and $V(I)$ curves were measured by the conventional 4-points technique, using a quantum design PPMS. A home-made pulsed-current set-up injecting triangular 1 ms pulses was also used to perform J_c measurements. In the (*J, H, T*) region where experimental conditions overlap, the results obtained by both measurement techniques (PPMS and pulsed current set-up) were found to agree with each other within 5% error bars. The critical current was extracted using a 1 μV/cm criterion.

3. Results

3.1. Electrical resistivity and irreversibility line

The temperature dependence of the electrical resistance of a thin slice cut from a single grain material is shown in Fig. 1. The data result from an injection current parallel to the *ab*-planes of the sample and several magnetic fields (0-5 T) applied parallel to the *c*-axis. As can be seen, all $R(T)$ transitions plotted on a log scale are very sharp, and without any intermediate step. This confirms the absence of weak links in the studied samples, and underlines a good average oxygenation level.

The data of Fig. 1 can be used for determining the irreversibility line (IL), i.e. the temperature above which the electrical resistance exceeds a given criterion (10^{-4} Ω). This *resistive* IL, plotted in the inset of Fig. 1, is compared to the *magnetic* IL measured on the same sample, and obtained by locating the field above which the

magnetization becomes reversible. Both methods nicely agree with each other. As highlighted by Caplin et al. [11], magnetic and transport techniques explore different regions of the *E-J* diagram. The electric field associated with transport measurements is given by dividing the sample voltage by the distance between voltage pads, whereas the surface electric field associated with an *M-H* loop measurement is given by $(a/2)\mu_0 dH/dt$, where *a* is the mean sample radius. In the present case, the *E* values for the transport and magnetic experiments are roughly equal to 10^{-5} and 10^{-6} V/m respectively. Their close value explains the very satisfactory agreement between results from both techniques.

Fig. 1. *Electrical resistance vs. temperature curves measured on a DyBCO single domain for several magnetic fields parallel to the c-axis and ranging (right to left) from 0 to 5 T. Inset: Comparison of the irreversibility lines extracted from R(T) (transport) data and determined using M(H) loop measurements.*
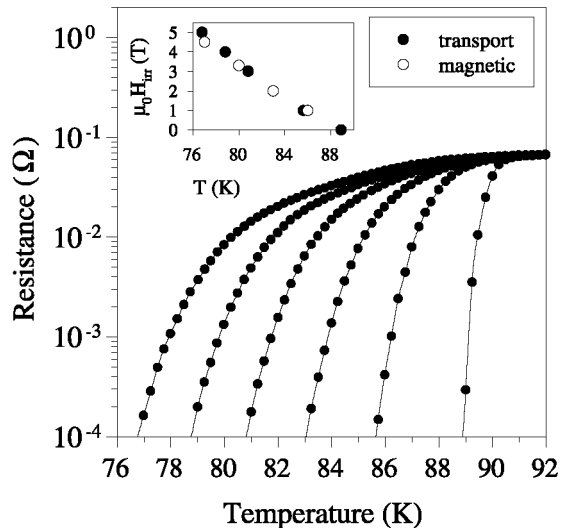
3.2. Magnetic measurements

Previous work [12] had shown that *M(H)* curves measured on several cubic samples of dimensions ~2x2x2 mm³ and extracted from the same single domain did not show any important variation of the magnetic properties as a function of location in the single domain. One of those sample was progressively cut into smaller pieces (typically 0.15 x 0.15 x 1.5 mm) intended for both transport and magnetic measurements. The magnetization curves measured on the original sample and on two such thin slices are compared in Fig. 2, for *T = 11* K and *H∥c*. One of the slices exhibits a very narrow magnetization curve and is therefore characterized by a poor J_c. Some hypotheses can be drawn in order to explain the reasons for such a degradation. We cannot exclude that some damage (cracks, ...) has occurred during the mechanical cutting process, but it must be pointed out that all samples were cut in the same way. Moreover, the eventual cracks are expected to be created parallel to the *ab*-planes, and therefore they do not have a significant influence on the shielding currents flowing in the *ab*-planes (*H∥c*). The AC susceptibility curves measured at low field (not shown here) did not display any significant T_c variation (~2 K) from one sample to another, which excludes a possible oxygen depletion. It is thus reasonable to believe that the J_c degradation observed in Fig. 2 might be caused by local inhomogeneities in the single domain.

Fig. 2. *Comparison of magnetization vs. magnetic field (H||c) curves, measured at T = 77 K on a DyBCO single domain (original sample) and thin slices cut from the main sample.*
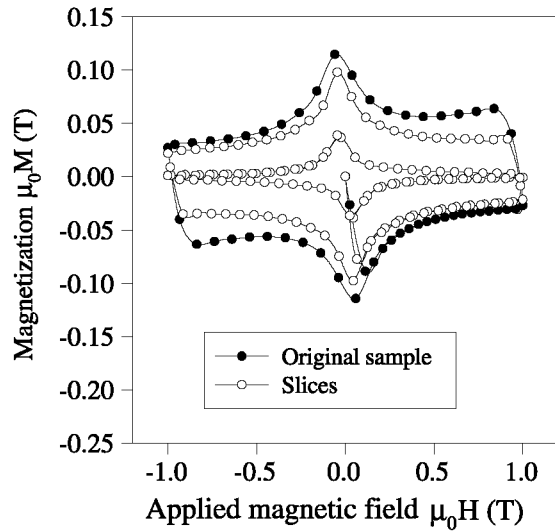
3.3. Critical current density

The intragranular *ab*-plane critical current density derived from *M*(*H*) measurements using the Bean model [13] is shown in Fig. 3. These *magnetic* J_c values are compared to the *transport* J_c. The transport J_c is seen to lie one order of magnitude below the magnetic J_c. As mentioned above, the electric field criterion used for defining J_c is more severe in the case of magnetic measurements, and should yield *smaller* magnetic J_c values, unlike the behaviour depicted in Fig. 3. Due to magnetic relaxation, the small time scales involved in the transport measurements (1 ms pulses) compared to magnetic measurements should also lead to smaller magnetic J_c's [14,15]. AC susceptibility measurements using a couple of parallel sensing coils have also shown [12] that geometric effects play a significant role when extracting J_c from the magnetic moment data, but such effects are likely to mainly affect the J_c measurements at relatively "small" magnetic fields ($\mu_0 H < 0.5$ T). The J_c inhomogeneities outlined above are thought to have a stronger impact for influencing the transport J_c than for determining the magnetic J_c [16]. Indeed low J_c regions are always short-circuited by the screening currents flowing along the sample edges.

Fig. 3. *Critical current density vs. magnetic field (H||c), determined by transport and magnetic measurements.*
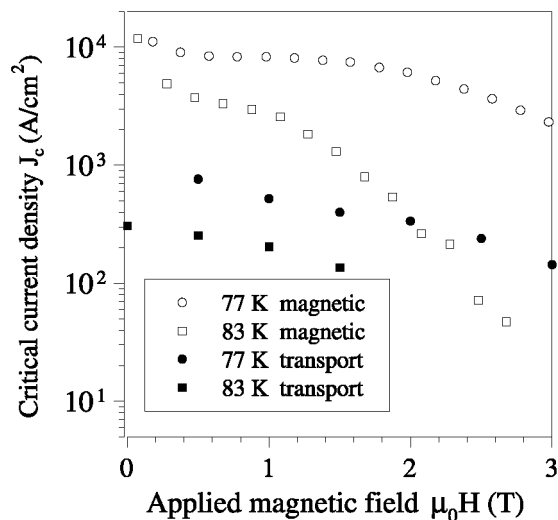
4. Conclusions

We have carried out transport and magnetic measurements on DyBCO single domains. The irreversibility lines determined by both methods were found to match each other. Comparison of magnetic measurements carried out on neighbouring samples cut from the same single domain brought out some J_c variations throughout the specimen. Such variations might be responsible for the fact that the transport J_c lies roughly one order of magnitude below the J_c calculated from magnetic measurements. Therefore we can conclude that magnetic J_c measurements may overestimate the local J_c within such DyBCO single domains.

Acknowledgements

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