

Detailed magnetisation study of inter- and intragranular currents in Ag-sheathed Bi-2223 tape

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Abstract. Magnetic hysteresis loops of a rolled Bi-2223/Ag tape were measured at various temperatures and fields up to ± 5 T. In order to separate the inter- and intragranular current contributions, the tape was bent to a small diameter and measured again after straightening. At low temperatures, a significant intergranular current hysteresis was observed for the increasing and decreasing field. Shapes of the experimental hysteresis loops are discussed in detail along with a deduced relationship between intergranular and intragranular currents.

1. Introduction

Ag-sheathed tapes of $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10-\delta}$ (Bi-2223/Ag) are known as favourite candidates for high power technical applications. Due to the granular nature of this superconducting material, two types of the critical currents are induced in the tapes: the intergranular currents and the intragranular ones. In spite of an enormous experimental and theoretical effort, relations between the inter- and intragranular currents are not fully understood yet.

Bending of an Ag-sheathed tape to a small diameter was recently suggested as a way how to separate the intergranular currents from intragranular ones [1].

The aim of the present paper is to study the inter- and intragranular currents in a Bi-2223/Ag tape at elevated temperatures by means of the bending method.

2. Experiment and discussion

The studied Ag-sheathed Bi-2223 tape was prepared by the standard powder-in-tube technique followed by rolling.

All measurements were performed in a Quantum Design's SQUID system MPMS-5S. The external magnetic field was always applied along the normal to the tape plane. We measured magnetic hysteresis loops (MHL) at temperatures from 5 K to 77 K and at field up to $B = \pm 5$ T. After bending the sample to diameter 1.25 mm and straightening it again, the measurement was repeated.

Magnetic hysteresis loops measured before and after the bending are plotted in figures 1(a) and (b). The most significant feature of the curves is the drop of magnetic moment after

the tape bending. Also the shape of the MHL is changed. The bending removes two anomalies observed originally in the tape:

- (i) Maximum of the magnetic moment lies no more at positive external fields and
- (ii) The MHLs become symmetrical at high fields and low temperatures.

The MHL maximum lying at positive fields contradicts the conventional scheme based on the assumption that the induced critical current reaches its maximum at zero magnetic field. As the internal magnetic field should lag behind the external one [2], the MHL maximum should lie at negative external fields on the descending field branch. Simple models of the intergranular current transport [3,4] do not account for this effect. Recently, Müller et al. [5] analysed position of the MHL peak in Bi-2223/Ag tapes and attributed the anomalous peak position to demagnetising effects (stray fields) arising from intragranular currents.

The asymmetry of the magnetic moment at low temperatures before the tape bending contradicts again the conventional ideas. It is characterized by the significantly higher (in absolute value) magnetic moment in the decreasing field than in the increasing field, in contrast to the traditional picture of a symmetric irreversible magnetic moment (due to flux pinning on defects) superimposed onto a negative equilibrium reversible moment. The simple model of Bean-Livingston surface barrier predicts just an opposite effect, i.e. the current in the decreasing field to be constant and much smaller than that in the increasing field [6,7].

Our present experiments show that both the above-mentioned anomalies are associated with intergranular currents and reflect the fact that at low temperatures these currents are limited by grain boundaries. After the tape bending, the MHL shape changes significantly and the anomalies disappear (fig. 1(b)). The MHL maximum shifts to the proper (negative) side of the field scale and no critical current suppression is observed during the field increase. As documented in figures 1(b) and 2, after the bending each MHL consists of a vertically symmetric irreversible contribution due to intrinsic pinning [2] and of an equilibrium reversible background. The intragranular currents rapidly decay with increasing temperature and field.

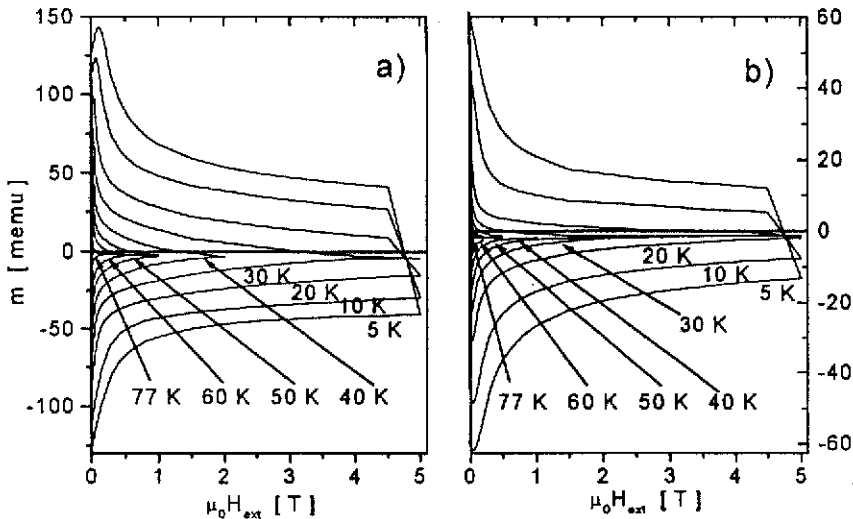


Fig. 1. Hysteresis loops measured in the Bi-2223/Ag tape before (a) and after (b) bending.

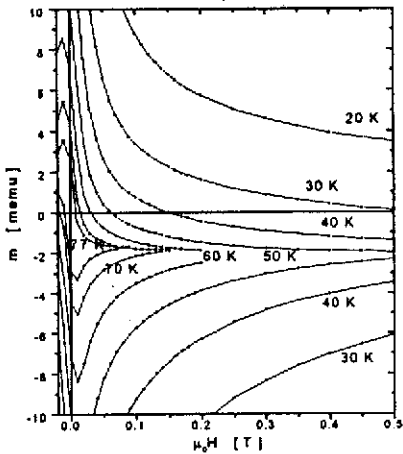


Fig. 2. Low-field parts of the MHLs of the bent tape for temperatures above 30 K.

In figure 3, we present hysteresis loops obtained by subtracting the hysteresis loops measured on the bent tape from those measured before the bending. These MHLs correspond to intergranular currents only. The two peculiarities observed on the MHLs before the tape bending are present on the "differential" MHLs, too. We conclude therefore that the intergranular currents are responsible both for the anomalous peak position and for the magnetic moment asymmetry in the decreasing and increasing field observed at low temperatures.

Below 30 K, the intergranular currents in decreasing field follow an $H^{-1/3}$ dependence (in agreement with Ref. [8]) (see inset in fig. 2). The intergranular currents in increasing field are practically field-independent at 5 K, however, with increasing temperature they become $\propto H^{-1/3}$. We emphasize that the field-

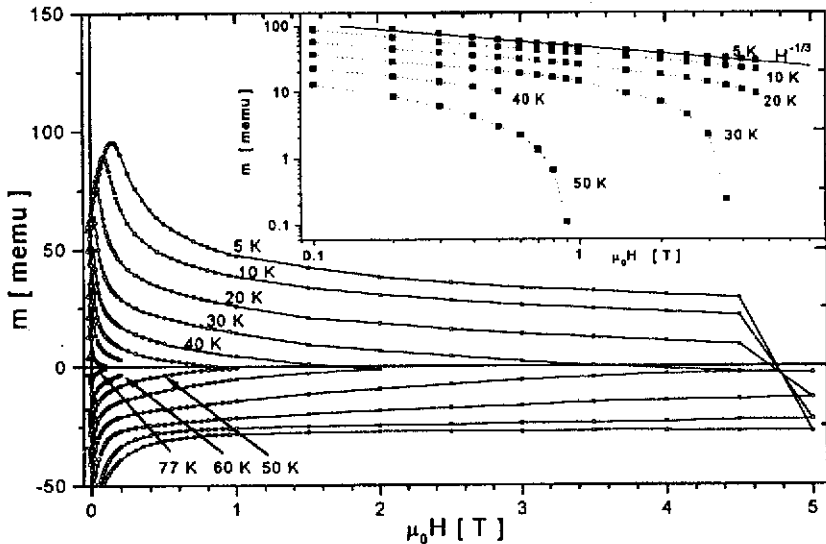


Fig. 3. Hysteresis loops related to intergranular currents. These curves were obtained by subtracting the MHLs measured after the bending from those measure before. Inset: Descending field branches (dotted) for low temperatures in a log-log scale.

independent intergranular currents in increasing field at 5 K agree with the results obtained by transport measurements [9] where the transport currents were found to be field-independent up to high fields.

The stray fields from the intragranular currents can result in an intergranular current hysteresis [5] but the magnitude of such an effect is much smaller than that observed in our sample at low temperatures. Another source of hysteresis may be Bean-Livingston surface barrier at grain boundaries [10]. The associated surface currents together with the inhomogeneous Josephson junctions may in principle lead to a field-independent current in the increasing field. However, the effects observed in Bi-2223/Ag tapes have different character from those attributed to Bean-Livingston surface barrier as observed on clean Bi-based single crystals [7]. Also the predicted $j_c \propto H^{-1}$ dependence is far from the observed $j_c \propto H^{-1/3}$. As discussed in [11-13], geometrical barrier can give rise to an asymmetry observed in the Bi-2223/Ag tape. The thermally activated vortices have enough energy to overcome such a barrier above 20 K. Thus, at higher temperatures the MHLs associated with the intergranular currents become symmetric.

3. Conclusions

Magnetic hysteresis loops measured on a Bi-2223/Ag tape before and after the tape bending to a small diameter were examined in detail. Two significant anomalies were observed on the MHLs before the bending, (i) the central peak on the MHL positioned at positive (descending) fields and (ii) the vertical asymmetry of the MHLs at temperatures below 20 K. Both these effects were shown to be connected with the intergranular currents. While the anomalous peak position could be explained by demagnetising effects of intragranular currents [5], the MHL asymmetry and especially the associated field independence of critical currents in increasing fields can hardly be due to a demagnetisation shift of the MHL branches [5]. Neither can they be attributed to Bean-Livingston barrier. The effect might be probably due to some kind of a geometrical barrier [11-13] leading to constitution of additional surface currents at grain edges.

Acknowledgements

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