Peculiarities of induced inter-granular currents in Bi-2223/Ag tapes

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Abstract

Two differently processed Bi_{2}Sr_{2}Ca_{2}Cu_{3}O_{10+x}/Ag 190 µm thick tapes were investigated as to the anomalous behaviour of the inter-granular currents induced by a change of external magnetic field applied parallel to the tape normal. We applied uniaxial stress to the compact, twice-rolled and twice-sintered tape, along its normal and observed how with increasing stress magnetic hysteresis loop (MHL) gradually changed from anomalous to regular. The average magnetic moment of the MHL branch, \( M_{av} = (M^+ + M^-)/2 \), changed from positive to negative. Above \( P = 1 \) GPa it saturated and started to change back. No anomaly appeared on the only once rolled and once sintered tape. The tape compression tests enables a quantitative description of the inter-grain links damage.

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In well-textured BiSrCaCuO silver-clad tapes the induced inter-granular currents often exhibit an anomalous field dependence [1–5] showing the central peak of magnetic hysteresis loop (MHL) anomalously shifted to positive decreasing fields and the MHL shifted upwards to positive magnetic moments. This effect was by Püst et al. [3] and Müller et al. [4] attributed to stray fields at edges of the flat grains aligned by their c-axes with the field direction, originating from demagnetisation of the grains and affecting the inter-granular currents.

To separate the inter-granular magnetic moment from the intra-granular one, bending of the tape to a small diameter has been commonly used [1,2,6]. However, this method does not allow for a quantitative analysis of the inter-grain link damage.

We studied the process of tape deformation by a gradual lasting of the tape by an increasing uniaxial stress along its normal. After each compression step, the magnetic hysteresis loop was measured at 7 K by a vibrating sample magnetometer. The results for a compact twice-rolled and twice-sintered tape 190 µm thick, P55B, (filling factor 38%) are shown in Fig. 1. The central peak of the MHL shifted with increasing stress from anomalous position at positive decreasing fields to the regular position at negative fields. Along with
that, also the MHL anomalous asymmetry with respect to the $b$-axis changed into commonly observed one.

As documented in Fig. 2, the average magnetic moment \( M_{av} = (M^+ + M^-) / 2 \) is better suited for detection of the anomaly than the total magnetic moment. In the anomalous unpressed sample \( M_{av} \) was positive at low temperatures (7 K) but \( M_{av}(B) \) transformed with increasing stress to a regular shape, similar to a reversible moment of single crystals. This process lasted up to the pressure of 1 GPa after which the curve started to shift back. This behaviour can be attributed to a plastic flow of the silver cladding and/or the grains’ $c$-axes alignment along the stress direction. The $c$-axis alignment would increase the net intra-granular moment contribution and thus compensate the inter-granular currents decrease. We defined the state at 1 GPa as a crossover between the regimes of prevailing inter-grain links destruction and grains alignment.

During the tape compression also the grain destruction might take place. To test this, we resolved the silver cladding of the intact tape P55B and of a part of the same tape pressed to 1.4 GPa and observed the effect of the stress on surface morphology of the tape by means of a scanning electron microscope. The average size of surface grains was nearly equal in both samples, which might be interpreted as practically no damage to the grains. One has, however, take into account grain-size variation throughout the tape and a possible difference in the grain morphology in the tape interior and on its surface. Therefore, the present conclusions need to be confirmed by a more detailed study.

For comparison, we studied another, less compact tape P56B produced in a similar way as P55B but only once rolled and once sintered. This sample in the intact state showed no anomaly. The \( M_{av}(B) \) curve at 5 K had the shape similar to that of the sample P55B pressed to 1 GPa (see Fig. 2). This indicated a significantly lower grain connectivity, which was also supported by transport current measurements at 77 K. The transport current of P56B was about 10 times lower than that of P55B.

In Fig. 3 we show \( M_{av}(B) \) of the intact tape P55B as a function of temperature. Above irreversibility field the MHL is closed and \( M_{av} \) coincides with reversible moment. At high temperature the irreversibility field is relatively low \( (B_{irr} = 0.2, 0.4, 0.7 \text{ and } 1.2 \text{ T for } 80, 70, 60 \text{ and } 50 \text{ K, respectively}) \). Above 50 K \( M_{av}(B) \) did not differ much from the reversible moment measured by field-cooling technique, \( M_{FC}(B) \), even well below \( B_{irr} \). \( M_{av} \) exhibited approximately logarithmic field dependence in intermediate magnetic fields and its magnitude increased with decreasing temperature as predicted by theory for reversible moment. Below 50 K, with the further increasing irreversibility field \( (B_{irr} = 2.3 \text{ and } 5 \text{ T for } 40 \text{ and } 30 \text{ K, respectively}) \), \( M_{av}(B) \) started to deviate from the regular behaviour in a wide field range. A strong positive
contribution appeared and shifted the curve to positive values. After the tape compression to 0.5 GPa the positive contribution was substantially reduced, due to reduction of inter-granular currents. This is a clear proof of the origin of the anomalies. A similar conclusion was made on basis of bending experiments [2,4,6].

It is interesting to compare the ‘irreversible’ average moment with the quasi-equilibrium moment $M_{FC}$ measured by means of SQUID by field-cooling and field-warming techniques at different constant field values. We stress that this moment was reversible, i.e. it had the same value for the given field and temperature both on field cooling and field warming. The temperature dependencies $M_{FC}(T)$ measured for a dense series of fields applied before cooling, at 120 K, were transformed into a series of field dependencies for different temperatures (Fig. 4). While above 70 K the curves were practically completely regular, for 60 and 50 K one could observe at low fields a start of a deviation to positive values. Appearance of this deviation well correlated with the irreversibility field range for all investigated temperatures. This deviation is thus related to flux pinning and a redistribution of originally uniform field during field cooling and field warming of the granular medium.

This effect is, however, completely reversible. Moreover, the $M_{FC}(B)$ curves for low temperatures became wavy, which effect was evidently sample-specific. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared. By the tape compression this waviness disappeared.

On two differently processed Bi-2223/Ag tapes we studied the effect of uniaxial stress on both the irreversible magnetic moment induced by a change of external field and reversible magnetic moment detected by field-cooling method. On the more compact tape P55B an anomalous MHL was observed that gradually transformed into regular one in course of the tape compression up to about 1 GPa. The average moment of the MHL coincided with field-cooled reversible moment beyond $B_{irr}$. Below irreversibility field, both moments exhibited anomalies of different types and behaviours.

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References


