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Physica C 408–410 (2004) 866–868
PHYSICA C
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Magnetic granularity analysis of YBCO coated conductors

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Abstract

We present an inductive analysis of a variety of YBCO coated conductors, based on complementary measurements of a.c.-susceptibility and d.c.-magnetization. The study addresses dissipation mechanisms associated with the grain boundary networks. We show that a.c.-susceptibility measurements are uniquely qualified to identify dissipative contributions from microstructurally inhomogeneous grain boundary networks.

Keywords: Electromagnetic granularity; Inductive measurements; Coated conductors

Coated conductors have emerged as one of the most promising materials for superconducting power applications. Many encouraging advances have been gradually reached in tape processing, however still the physical mechanisms for current percolation and flux dissipation are not fully understood. Questions related to homogeneity of the grain boundary network dissipation, advantages of ion-beam-assisted deposition (IBAD) substrates versus rolling-assisted biaxially-textured substrates (RABiTS) and thickness dependence of the critical current density, remain open. An inductive analysis based on complementary measurements of d.c. magnetization and a.c.-susceptibility is considered as a potential route to improve the understanding. In this contribution, we present a.c.-susceptibility and d.c.-magnetization measurements of different kinds of IBAD and RABiTS coated conductors. Sample details are given in the figure captions.

The inductive magnetization measurements were carried out with a standard SQUID Magnetometer provided with a 5.5 T superconducting coil. For the a.c. susceptibility measurements we have used a standard PPMS magnetomenter/a.c.-susceptometer from Quantum Design provided with a 9 T superconducting coil. All measurements were performed by zero field cooling the sample and the magnetic field was applied perpendicular to the sample surface. Appropriate care was taken to subtract the substrate signal in each case.

Fig. 1(a) and (b) shows the temperature dependence of the imaginary component of the a.c. susceptibility, χ'', of two coated conductor tapes, IBAD-a and RABiTS-a. The value χ_0, used in the normalization, is the initial susceptibility $\chi_0 = 8R/3\pi d$, where R and d are the sample radius and YBCO thickness respectively [1].

χ'' takes into account hysteretic losses of the superconductor when flux penetrates the film and a peak is observed when the flux profile reaches the center of the sample. For thin films, according to the Bean critical state model, at the peak position, $\chi''_{peak} = 0.241\chi_0$ [1]. The value of χ''_{peak} for cylinders of different aspect ratio, 2R/d (Fig. 2), can be calculated by using a numerical model based on energy minimization [2]. Comparison of

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0921-4534/$ - see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.physc.2004.03.224

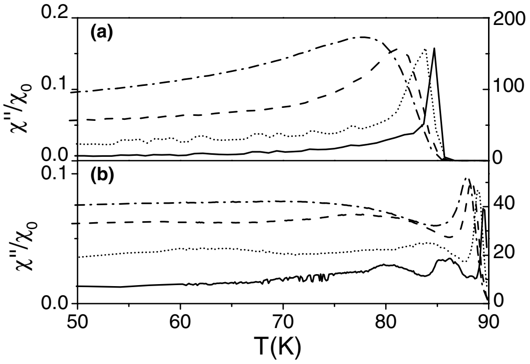

Fig. 1. Temperature dependence of the imaginary component of the a.c.-susceptibility, χ'', and the normalized value, $\chi''/\chi o$, for an a.c. field amplitude of 8, 80, 400 and 800 A/m at 1111 Hz for (a) IBAD-a: 1.6 μm thick YBCO/YSZ/stainless steel deposited by high rate PLD [3], (b) RABiTS-a: 2.4 μm thick YBCO/CeO2/YSZ/Y2O3/Ni/NiW grown by a BaF2 ex situ process using evaporated precursors [4].

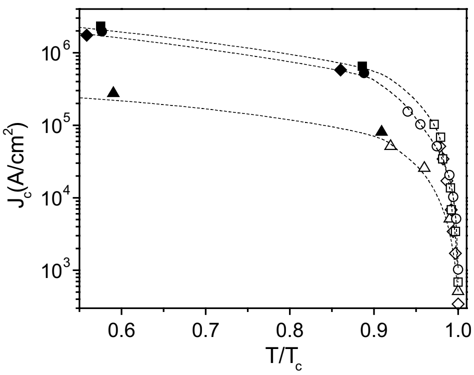

Fig. 3. Temperature dependence of the critical current density, J_c, determined from the ac-susceptibility data (open symbols) for IBAD-a (△), IBAD-b (□): 1.2 μm thick YBCO/CeO_2/YSZ/SS deposited by high rate PLD [3], RABiTS-a (◇) and RABiTS-b (○): 0.8 μm thick YBCO/YSZ/CeO_2/Ni–Mn deposited by standard PLD process [6]. Also shown are he results obtained from d.c.-magnetization (closed symbols).

the experimental χ''_{peak} values with the results of the calculations enables us to clearly identify the grain boundary network as the source of dissipation ($R/d \sim 50$–150, i.e. R ~sample radius). The dissipation associated with the grains (0.5 μm< R <50 μm) should give a negligible signal ($0.25 < \chi''_{peak} < 10$).

Notice however that $\chi''_{peak}/\chi_0 \sim 0.17$ and 0.1 for the IBAD-a and RABiTS-a samples respectively, instead of the expected 0.241. This result evidences that in both cases only a fraction of the whole sample dissipates at the peak. The remaining fraction should be associated with the dissipation tail observed at lower temperatures for the case of IBAD-a or likewise the smaller peaks observed at lower temperatures for RABiTS-a. The ac-susceptibility measurements are able to detect a main dissipation peak arising from the flux profile penetration through the grain boundary network to the center of the

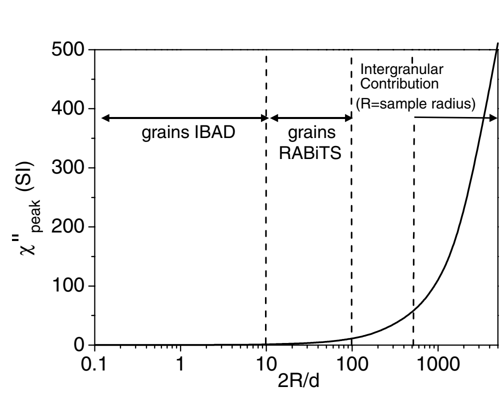

Fig. 2. Calculated maximum value of χ'', χ''_{peak}, for different cylinder aspect ratios $2R/d$.

sample and secondary dissipation coming from small areas probably located near the sample edge with clearly lower J_c.

Similar measurements performed on a YBCO IBAD tape known to have a very homogeneous GB network (IBAD-b, see Fig. 3), confirmed that $\chi''_{peak}/\chi_0 \sim 0.24$, showing that in this case the whole sample is contributing to the peak dissipation.

We have also determined the critical current $J_c(T)$ from the a.c. measurements in the Bean critical state model by using the analytical thin film approximation [1].

$$J_c(T_{peak}) = 2H_{a.c.}/x_t d \quad (2R/d > 100)$$

where x_t is a dimensionless factor with value $x_t = 1.94$, and $H_{a.c.}$ is the a.c.-field amplitude.

The results obtained for IBAD-a (△), RABiTS-a (◇) and IBAD-b (□) samples, are shown in Fig. 3 (open symbols). Also shown are the results for another RABiTS sample, RABiTS-b (○). Also included (closed symbols) are $J_c(T)$ values obtained from the d.c.-magnetization methodology described elsewhere [5] for the same samples.

Similar results are obtained for the IBAD-b, RABiTS-a and RABiTS-b tapes, with a ϕ-scan full width at half maximum (FWHM) of 6.3°, 6.6° and 5.3° respectively, whereas a much lower $J_c(T)$ curve is obtained for the IBAD-a which had relatively poor texture (ϕ-scan FWHM = 12.7°) and some secondary colonies with misoriented grains at 45°.

The variation in J_c observed for the samples with similar in-plane texture of the YBCO could be associated to different YBCO thickness, deposition techniques and grain boundary quality or distribution. In case of IBAD-a, the low texture quality is the dominant factor ascribed to the reduction of $J_c(T)$.

In conclusion, a.c.-susceptibility measurements of a variety of IBAD and RABiTS tapes have been performed, showing potential for quantitative analysis of the magnetic granularity of coated conductors.

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