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Grain boundaries in coated conductors: still an issue at low temperatures?

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***Abstract*— The manifestation of grain boundary (GB) limitation through transport and magnetic measurements in different coated conductor (CC) architectures below liquid nitrogen temperatures was investigated. With the strong GB limiting effects in pulsed laser deposited (PLD)-YBCO on Ni5at%W substrates, an interesting behavior in the field-dependence of the critical current density, $J_c(B)$, and in its anisotropy, $J_c(\phi)$, was observed. These results lead to further knowledge on the collective behavior of the grain boundaries to the percolative current flow in coated conductors, which becomes more significant to its performance at lower temperatures.**

I. Introduction

Grain boundaries (GBs) are one of the challenges in optimizing the current-carrying capacity of high-temperature superconductors. To reduce the limiting effect of GBs in coated conductors (CCs), much work has been done to develop growth methods that minimize the misalignment between superconducting grains thus avoiding a strong decrease of J_c. The use of biaxially textured substrates or textured buffer layers has prompted long-length production of tapes with self-field J_c of several MA/cm^2 at 77 K [1]. Most of the produced coated conductors (CCs) have optimized performance at 77 K and the effect of the GBs is observed only at low fields. Therefore, more focus was given on improving the performance of CCs at high magnetic fields by engineering the vortex pinning landscape. However, the growing demand of large magnetic fields has called for the operation of coated conductors down to 4.2 K and the effect of the GBs is amplified as the temperature decreases [2]. In this paper, we aim to investigate the effects of the GBs at low temperatures in different coated conductors by transport and magnetization measurements as well as scanning Hall probe microscopy.

II. Methodology

A. *The coated conductors*

Coated conductors with different YBCO grain boundary structure were studied. Two tapes have the YBCO layer grown by pulsed laser deposition (PLD). The first tape was on a rolling assisted biaxially textured substrate (RABiTS) Ni-5at%W with chemically deposited CeO_2 and PLD-$La_2Zr_2O_7$ buffer layers. The second tape had an alternating beam assisted deposition (ABAD) textured buffer layer composed of Yttria stabilized Zirconia (YSZ) and PLD-CeO_2 on a stainless steel (SS) substrate. Whereas Ni-5at%W tapes have an average grain size of 25 µm, the grain size of the ABAD-SS template was below 1 µm. PLD-grown tapes are known to have almost planar grain boundaries [3, 7]. Chemical solution deposition (CSD) was used to grow the YBCO layer on another RABiTS-Ni-5at%W substrate. This ex-situ growth method yields meandering grain boundaries [3, 7]. The three coated conductors have similar YBCO layer thickness of about 1.5 µm. A ~300-µm bridge was patterned in each tape for transport J_c measurements.

B. *Characterization Techniques*

Scanning Hall probe microscopy (SHPM) was used to image the magnetic field profiles with applied magnetic fields up to 5 T and temperatures down to 4 K. The magnetic field was applied perpendicular to the surface of the tape and the measured local field B was also in the same direction. The resolution of the scans was about 2 µm. The dependence of J_c on field was obtained by transport and magnetization measurements. A vibrating sample magnetometer (VSM) equipped with a 5 T superconducting magnet was used to measure magnetization loops at which $J_c(B)$ was evaluated. Transport J_c was measured using the four probe method and evaluated with an electric field criterion of 1 µV/cm. The cryostat used was equipped with a 6-T superconducting magnet. Angle-resolved transport J_c was obtained in maximum Lorentz force configuration.

III. Results and Discussion

Figure 1 shows the remanent field profiles at 4 K of the two PLD-grown tapes. The trapped field in the CC on Ni-5at%W (NiW) substrate is formed into clusters, which is directly correlated with the granular structure of the deposited YBCO layer. This behavior persists even in magnetic fields up to 5 T and higher temperatures (not shown here). On the other hand, the CC on ABAD-SS template has a smooth profile that is attributed to the smaller grains and better texture of the YBCO

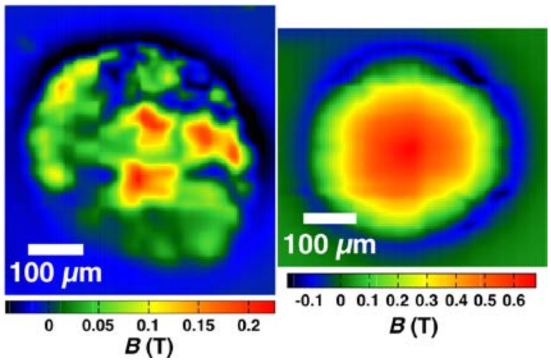

Fig. 1. Remanent field profile at T = 4 K of the CCs on RABiTS-Ni5at%W substrate (left) and ABAD-SS substrate (right).

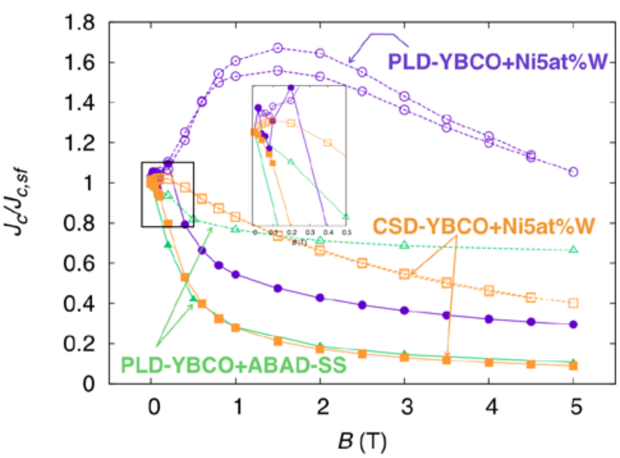

Fig. 2. Comparison of the transport $J_c(B)$ of the three CCs at T = 40 K. Filled symbols denote $J_c(B)$ at $H_{app} \parallel c$ while the hollow symbols denote $H_{app} \parallel ab$. The inset shows an enlarged view of the field between 0 to 0.5 T.

layer. The pronounced granularity of the magnetic field profile of the PLD-YBCO on NiW tape at 4 K implies that J_c is strongly limited by the grain boundaries.

In relation to the strong GB limitation observed in the SHPM images, bridged PLD-YBCO on NiW tapes with width below the critical limit of number of grains with reduced J_c [4] was examined by transport measurements. As shown in Fig. 2, the PLD-YBCO on NiW has a peak around 1.5 T leading to a 70% larger J_c at this field than its self-field value, $J_{c,sf}$, at 40 K. This peak appears both in increasing and decreasing field for $H_{\mathrm{app}} \parallel ab$ and occurs at larger field as the temperature is decreased. Some papers have reported the appearance of a peak in the transport $J_c(B)$, but it is interesting to note that they have observed this only with decreasing field and at low fields of a few tens of mT ($H_{\mathrm{app}} \parallel c$ in that case) [5]. Correspondingly, the angular dependence of J_c for the PLD-YBCO on NiW has an almost flat, angle-independent region around the $H_{\mathrm{app}} \parallel ab$ direction as shown in the normalized plot in Fig. 3 at T = 40 K and $\mu_0 H_{\mathrm{app}}$=0.5 T. J_c exceeds $J_{c,sf}$ in a certain angular range around $H_{\mathrm{app}} \parallel ab$.

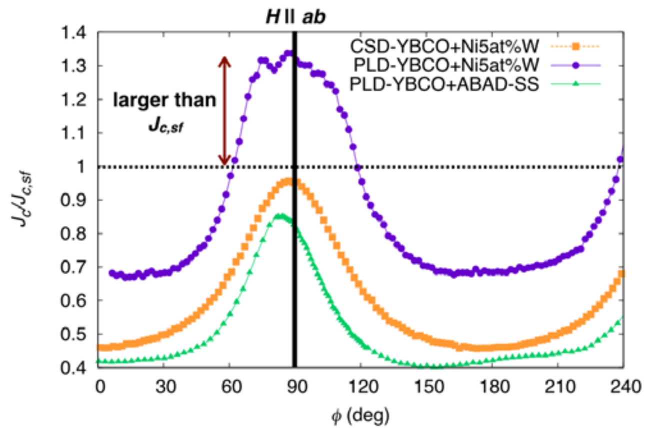

Fig. 3. Angular dependence of J_c of the three CCs at T = 40 K and $\mu_0 H_{app}$ = 0.5 T. The data was normalized by the self-field J_c of each tape at 40 K.

One can then expect that the planar GBs of PLD-grown tapes have a stronger effect in limiting current flow as compared to tapes with meandering GBs such as the CSD-YBCO on NiW [6]. As observed in the inset in Fig. 2, the CSD-YBCO on NiW tape has a very small trace of a peak in $J_c(B)$ at around 100 mT in $H_{\mathrm{app}} \parallel ab$ direction. On the other hand, the $J_c(\phi)$ does not exceed $J_{c,sf}$ at all ϕ but approaches its value near $H_{\mathrm{app}} \parallel ab$ (Fig. 3). For the PLD-YBCO on ABAD-SS, the behavior that can be accounted to GB limitation is not observed. $J_c(B)$ decreases monotonously with increasing field and $J_c(\phi)$ has the usual anisotropic behavior.

IV. Conclusions and Further work

By comparing different coated conductors with different grain boundary structures, GB effects were identified by transport measurements and supported by SHPM images. As the temperature was decreased, the limitation became more significant and occured up to a few Tesla, which was observed in PLD-YBCO on NiW. The effects in CSD-YBCO on NiW tapes were not as distinct as in PLD-YBCO and were almost absent in PLD-YBCO on ABAD-SS owing to its smaller grains (the width of the bridges patterned were above critical limit that induces reduction of J_c) and better texture of the YBCO layer. Further work has to be done to understand the mechanism that governs the grain boundary limitation that seems to depend on the orientation of the applied field with respect to the sample.

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