

Critical current in PLD-YBCO coated conductors investigated by high-resolution Hall scan measurements

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The limitation of the global critical current density resulting from low angle grain boundaries (LAGBs) in magnetic fields and low temperatures is still one of the open issues for high-temperature superconductor wires and tapes. The growing demand on generating large magnetic fields and the suitability of (RE)Ba₂Cu₃O₇ (RE = rare earth element) coated conductors (CC) call for the optimization of the current-carrying capacity of these materials at low temperatures. A lot of research has been devoted on the vortex pinning landscape that enhances the critical current density, J_c , and minimizes its anisotropy [1, 2]. However, grain boundaries with low misorientation angles (i. e. $< 10^\circ$) are always present and either contribute to pinning [3] or limit current flow and decrease J_c [4]. The main goal of this work is to determine at which magnetic fields and temperatures GBs limit J_c of CCs.

We use scanning Hall probe microscopy (SHPM) as a straightforward technique that allows the direct imaging of the magnetic field profiles of superconducting films and tapes. The measured field profiles provide information on the homogeneity of the superconducting layer. The spatial variation of J_c can be calculated from the field profile by implementing an algorithm that inverts the Biot-Savart law [5].

In this work, YBa₂Cu₃O_{7- δ} (YBCO) coated conductors grown by pulsed laser deposition (PLD) technique on a rolling assisted biaxially textured (RABiT) NiW substrates were investigated. The Ni-5at%W has chemically deposited La₂Zr₂O₇ and CeO₂ buffer layers while PLD-Y₂O₃/YSZ/CeO₂ was used for the Ni-9%W tape. The SHPM is equipped with an 8 T superconducting magnet in a He gas flow cryostat where the temperature can be stabilized between 3 K and 300 K. The spatial resolution of the SHPM in xyz-directions is about 1 μ m stepwidth with a similar distance of the Hall probe to the sample surface. Another scanning Hall probe device was used to measure remanent field profiles in a liquid nitrogen (LN₂) bath with a lower resolution of $\geq 50 \mu$ m where the distance between the Hall probe and the sample is $\approx 15 \mu$ m.

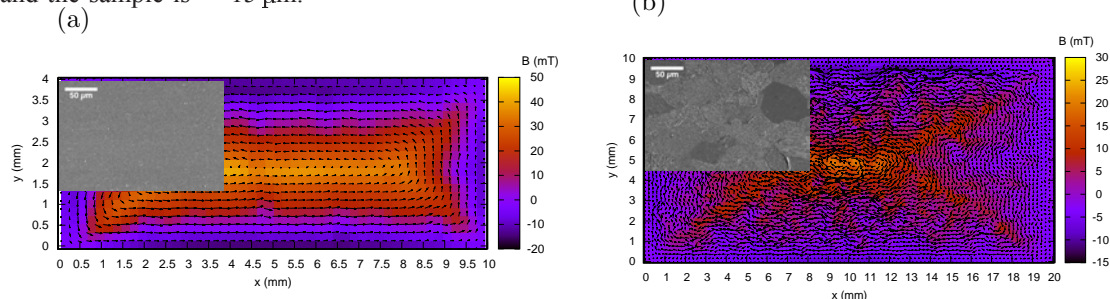


Figure 1: Remanent field profiles of PLD-YBCO on (a) ABAD-SS substrate and (b) Ni-5at%W substrate in LN₂ (stepwidth of 200 μ m). The arrows illustrate the current flow obtained by inversion of the field profile. The insets show SEM images of the sample surfaces.

Figure 1 shows the trapped field profile of two PLD-YBCO samples in LN₂. YBCO-NiW tapes are known to have large superconducting grains in the range of 20-80 μ m as shown by the scanning electron microscope (SEM) image in the inset of Figure 1b. Their field profiles show more granularity than the PLD-YBCO tape in Figure 1a, which is based on a stainless steel substrate with a YSZ buffer layer produced by alternating beam assisted deposition (ABAD-YSZ). This fabrication technique results in an average grain size of 0.7-1.1 μ m (Figure 1a). Further confirmed by a higher resolution Hall scan image of a PLD-YBCO spot on Ni9%W (Figure 2), instead of a global current flow around the whole superconducting area, the current percolates locally around a grain or cluster of grains.

To determine what property of the superconducting layer dictates the local current flow, the remanent field profile of a small PLD-YBCO spot with a diameter of $\approx 120 \mu$ m was measured and compared to an electron backscatter diffraction (EBSD) map of the same spot as shown in Figure 3. The EBSD

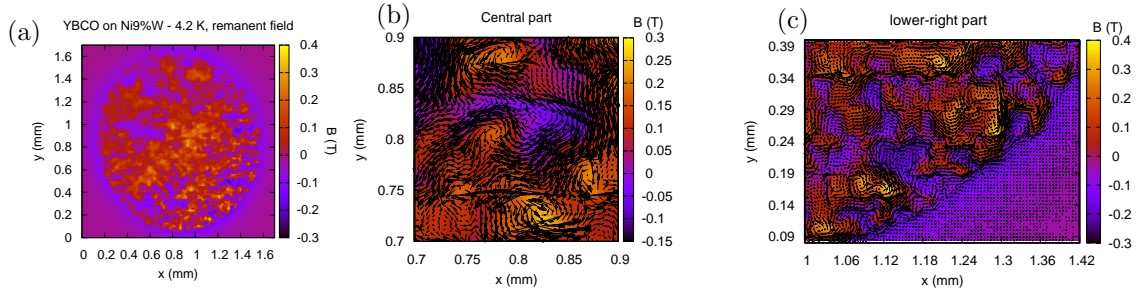


Figure 2: (a) Remanent field profile of a YBCO spot on Ni9%W at 4.2 K. The scan has a stepwidth of 10 μm . Enlarged areas in the (b) central part and (c) lower right part are shown with the J_c vector maps to illustrate the local current flow within grains and clusters of grains.

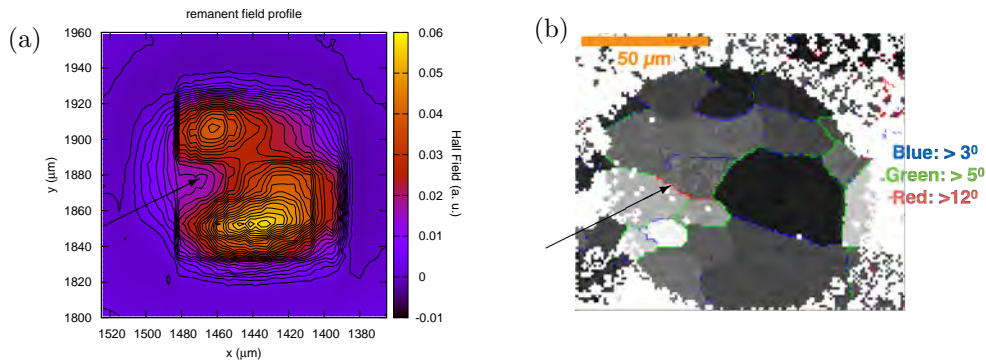


Figure 3: (a) Remanent field profile of a $\approx 120 \mu\text{m}$ YBCO spot on Ni5%W substrate at 4.2 K and scan stepwidth of 3 μm . (b) The corresponding EBSD map of the same spot showing the grain boundary misorientation angles and single grain orientation.

map shows the grain boundary misorientation angles and the orientation of YBCO in a single grain. By comparing these two images, it is evident that the cluster of magnetic grains is separated by a boundary with a misorientation angle of 5° and only a weak magnetic field was detected in the area with large grain misorientation. A large angle grain boundary is denoted by a black arrow in Figure 3.

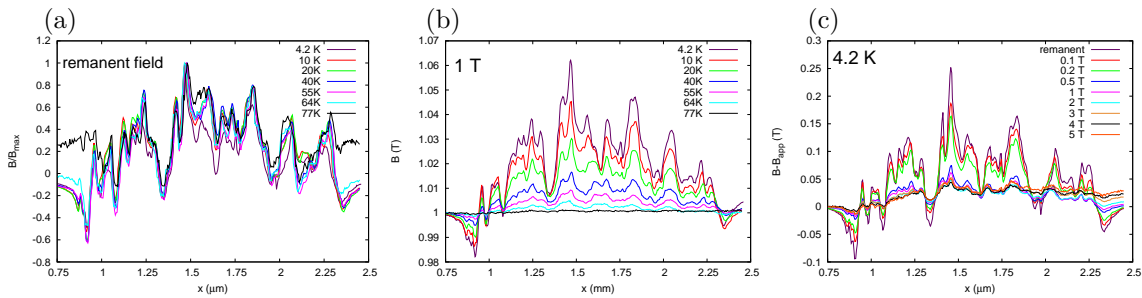


Figure 4: Linescans at $y=0.8 \text{ mm}$ of the 2-mm YBCO spot of figure 2 at (a) remanent state at different temperatures, (b) with an applied magnetic field of 1 T and different temperatures and (c) at $T = 4.2 \text{ K}$ and different applied magnetic fields.

Line scans were done above the YBCO spot of Figure 2. Each scan is made along the x -direction at $y=0.8 \text{ mm}$. The granular structure of the field profiles shown in Figure 4a-c persists at temperatures up to 77 K and applied fields of up to 5 T. In the remanent state (Figure 4a), the variations at the magnetic boundaries are almost the same from 64 K down to 4.2 K. With an applied field of 1 T (Figure 4b),

one can see that the peaks are amplified due to the larger superconducting signal at lower temperatures. However, the boundaries do not disappear even at higher temperatures (i. e. 77 K). At 4.2 K (Figure 4c), the granular texture of the profile is also found to persist up to an applied field of 5 T. These results clearly show that the limitation of the boundaries formed between clusters of grains or single grains indeed limits the J_c not just at lower fields but also in a wider range of field and temperature.

In summary, with the high resolution SHPM measurements on PLD-YBCO tapes with RABiT NiW substrate (both on magnetic Ni5%W and non-magnetic Ni9%W), the granular texture of the deposited YBCO layer was resolved in the magnetic field profile. The granularity in the field profiles was found to appear at all fields and temperatures.

References

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