Microstructure and surface roughness influence on magnetic flux penetration behavior in mono and multilayer YBCO thin films

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The study of local flux distribution in YBCO thin films via the magneto-optical (MO) technique shows that surface roughness and microstructure, as well as the size and nature of inhomogeneities influence the flux penetration behavior. In addition, the MO technique gives new insight on the high critical current density multilayer YBCO thin films.

1. Introduction

With a critical current density (J_c) reaching over 10^{11} $A.m^{-2}$ at 10 K, YBCO films are among the best candidates for the manufacture of superconducting wires (coated conductors). Unfortunately, this high J_c value has been shown to decrease when the thickness (d) increases above $d>2\lambda$ (λ being the London penetration length) [1-2]. The surface roughness and microstructure of the sample have also been shown to influence the J_c [2-5].

To counterbalance the degradation of J_c with an increase of d, multilayer films have been developed [6]. Global magnetic measurements on such films show a significant increase of J_c as well as a drastic improvement of the surface roughness. In this work, a set of monolayer films produced by pulsed laser deposition (PLD) along with a multilayer film prepared by the same technique was studied with the help of the magneto-optical (MO) imaging technique. The use of MO imaging allows us to visualize the effect of these improvements on the local magnetic field and current distributions in the films. Two YBCO thin films produced by magnetron sputtering and metal-organic deposition (MOD) with very different microstructures were studied as well.

2. Experiments

The monolayer films with different thickness, produced by PLD, will be further refereed as P1 (d=345nm), and P2 (d=1820nm). The (Y/Nd)BCO multilayer sample P3 with three ~280 nm thick YBCO layers and two intermediate ~30 nm thick NdBCO layers is also produced by PLD, with a total thickness ~ 800nm. The details of the fabrication can be found in [6]. The sample labeled K1509 was produced via the magnetron sputtering method [7] and had a thickness of 400nm whereas the MOD technique was used to deposit the thin film MOD17 [8] with d=200nm.

The surface roughness and microstructure were investigated with a Scanning Electron Microscope (SEM). Global magnetic measurements were carried out by a SQUID magnetometer in perpendicular field on all samples but MOD17. To study the local magnetic behavior, the MO imaging technique was used by placing a magneto-optically active crystal loosely on the top of the thin film and applying the magnetic field perpendicularly to the film plane. In the obtained images, the brighter the area, the higher the magnetic flux is [9].

3. Results and discussion

Fig. 1 shows the SEM pictures of the studied samples. The surface of the PLD samples appears much smoother than for the samples K1509 and MOD17, in particular in the case of the multilayer film P3 (Fig.1 c). In addition, P1 and P2 have some holes in the structure, whereas MOD17 is substantially porous.

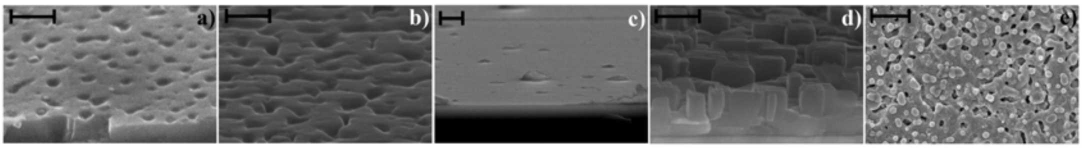

Figure 1. SEM pictures of sample P1 (a), P2 (b), P3 (c), K1509 (d) and MOD17(e), the scale bar on each image corresponds to 1μm.

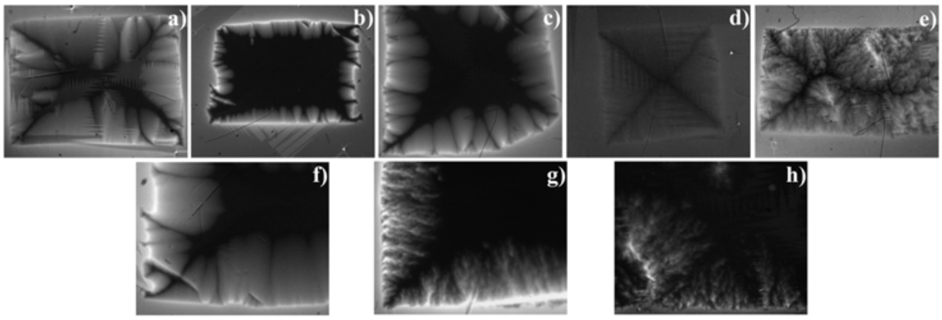

Figure 2. MO images at 77.7K and 11mT of P1 (a), P2 (b), P3 (c), K1509 (d) and MOD17 (e), the pictures f), g) and h) are images taken with a higher magnification of sample P2 at 77.7K and 21.9mT, sample K1509 at 5K and 32.9mT and sample MOD17 at 77.7K and 5.5mT respectively. Images a) to e) are 3.2mm wide while images f) to h) are 1.9mm wide.

Fig. 2(a-e) shows typical MO images of the 5 samples at 11mT as well as the detail of penetration flux patterns at high magnification (f-h) for the samples P2, K1509 and MOD17 respectively. The penetration pattern, influenced by the microstructure and the surface roughness of the films, clearly appears smoother in the films produced by PLD. However, it is to be noted that, although the surface topography greatly change from sample P1 and P2 to sample P3, no change in flux behavior is apparent. The difference of the size of inhomogeneities in the samples (in P1 and P2, the diameter of the holes ≈0.3μm whereas in K1509 the average size of the islands ≈0.8μm) can greatly affect the flux penetration patterns as shown in [2] and could explain the different penetration behavior between P1 and P2 on one side and K1509 on the other. The finger like penetration patterns in MOD17 could be caused by its porous microstructure creating weak superconducting areas in addition to its rough surface.

From the MO observation, and after a careful calibration in field, the distribution of supercurrents was estimated. From these estimations, sample K1509 show the lowest local J_c^{MO} magnitude, in agreements with the global magnetic measurements. The J_c value was found to be of 1.36×10^{10} A/m^2 in zero applied field and at 77K compared to J_c values ranging from 1.66×10^{10} A/m^2 to 2.1×10^{10} A/m^2 in the samples produced by PLD. No global magnetization measurements are available for the sample MOD17.

In the particular case of the three samples produced by PLD, the J_c^{MO} magnitude obtained through calibration and calculation from the MO images shows a higher J_c in sample P1: 3.7×10^{10}A.m^{-1} against 1.3×10^{10}A.m^{-1} for P2 and 1.9×10^{10}A.m^{-1} for P3. These findings are in apparent contradiction with the global magnetic J_c measurements, which show that P3 significantly outperforms P2 and P1 at 10 K [6].

The high temperature of MO observation could be a key factor to explain these puzzling results. Indeed, as shown in Fig.3a, the magnetic J_c of P3 is decreasing much faster with increasing temperature than samples P1 and P2. This could be due to the fact that the optimal temperature for deposition of NdBCO films is at least 50°C higher than YBCO [6]. This is likely to lead to rapidly degrading superconductivity in NdBCO with increasing temperature, which can be seen for M(T) curves for NdBCO and YBCO deposited at the same temperature

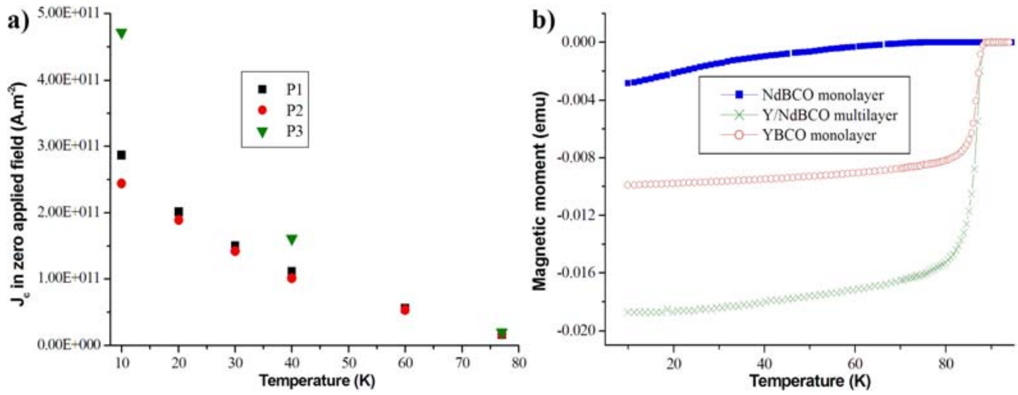

Figure 3. a) Magnetic J_c as a function of the temperature for the three samples produced by PLD, b) Magnetic moment as a function of the temperature for P3 and NdBCO and YBCO monolayer films deposited in the same conditions.

as the entire sample P3 (Fig.3b). The transition is much broader for NdBCO, hence this layer would act as a weak superconductor at 77.7K, causing a "decoupling" of the YBCO layers. This would explain the lower values of J_c^{MO} obtained from the MO images for sample P2 and P3 as the MO technique enable to visualize the penetration behavior only in the topmost layer of the film.

4. Conclusion

The microstructure, surface roughness, as well as the size and nature of inhomogeneities were shown to influence the flux penetration patterns in YBCO thin films. Local flux measurements do not give the expected higher J_c in the multilayer film when compared to monolayers. The non-optimal deposition temperature for the intermediate layers of NdBCO in the multilayer film led to degradation of superconductivity at 77.7K in these thin layers. This caused the YBCO layers to behave as weakly coupled layers. More work is necessary to find a more suitable range of deposition temperatures for NdBCO or other ReBCO superconductor with more suitable deposition parameters than NdBCO.

Acknowledgements

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