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Comparison of the critical current density of YBCO films obtained by dc sputtering and pulsed laser deposition

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We measured the critical current density J_c of optimally doped $YBa_2Cu_3O_{7-\delta}$ thin films obtained by dc sputtering on (100) oriented $SrTiO_3$ substrates and by pulsed laser deposition (PLD) on (100) oriented MgO substrates with $SrTiO_3$ buffers. J_c at various temperatures T was determined from the magnetization curves registered with a vibrating sample magnetometer for an external magnetic field H (oriented along the c axis) up to 90 kOe. It was found that J_c of the films obtained by PLD usually overcomes the J_c values of the sputtered films in the whole investigated (H, T) domain.

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1. Introduction

The importance of high-temperature superconductors (HTS) with strong vortex pinning comes from their ability to carry large transport currents in the presence of a magnetic field even at liquid nitrogen temperature. Natural pinning sites are usually not periodically distributed. If the vortex system would be perfectly periodic and rigid, it could not be effectively pinned by any random collection of pinning sites [1]. Then an applied current would lead to Lorentz forces on vortices and induce flux movement accompanied by energy dissipation. However, the vortex assembly is not rigid but the inter-vortex interactions allow easily elastic deformations. Thus the vortex system can adapt to the spatial distribution of the pinning sites to minimize its energy. In this case, for small currents the pinning force opposes the Lorentz force and dissipation free current transport is possible. For very strong currents vortices are depinned and the flux motion is damped by viscous forces predominantly, in the so called flux flow regime. In the intermediate current range the behavior is complex especially if pinning energies, elastic energies and the thermal energy are comparable. In the flux creep regime the thermal activation induces flux movement. This can be in form of motion of individual vortices and dislocations or, in case of interacting vortices, flux line bundles move. As vortices are line objects their longitudinal correlation along the magnetic field direction is generally much stronger than the transverse correlation, leading to different elastic moduli of the flux line lattice for tilt and shear deformations.

In anisotropic systems like the layered HTS the crystalline anisotropy also strongly influences the vortex system. For optimally doped $YBa_2Cu_3O_{7-\delta}$ (YBCO) the effective mass of charge carriers moving along c direction is approximately 50-100 times larger than that for the movement in the (a, b) plane, leading to an anisotropic vortex system. In the case of $Bi_2Sr_2CaCu_2O_{8+\delta}$, for example, the anisotropy is much stronger, leading to an effectively two dimensional vortex assembly consisting of “pancake vortices” instead of three dimensional vortices [2].

In this work we measured the J_c values of YBCO films obtained by dc sputtering (YBCO S) or pulsed laser deposition (YBCO PLD). The deposition parameters were optimized for the highest zero-field critical temperature T_c, which was ~91.5 K for the sputtered films and ~90.3 K for the films obtained by PLD. It was found that the critical current density J_c of the films obtained by PLD usually overcomes the J_c of the sputtered films in the whole investigated (H, T) domain.

2. Experimental results and discussion

The investigated specimens were rectangular or disk-shaped optimally doped films, with the (a, b) plane area of a few mm^2. The measured YBCO PLD were prepared on (100) oriented MgO substrates with $SrTiO_3$ buffers [3], using a Lambda Physik KrF excimer laser (λ = 248 nm) at an energy of 340 mJ/pulse and an oxygen partial pressure of 200 mTorr. The measured YBCO S films were prepared by dc sputtering on (100) oriented $SrTiO_3$ substrates, at a nearly equal oxygen partial pressure. The substrate temperature was 810 °C for YBCO S and 800 °C in the case of YBCO PLD. Afterwards, all the films were cooled to room temperature within one hour in 500 Torr of oxygen, which may assure an optimum oxygen doping level [4]. T_c was determined by ac susceptibility measurements, with H = 10 Oe applied along the c axis. The YBCO S films have the thickness of ~200 nm, whereas the YBCO PLD films were ~310 nm thick.

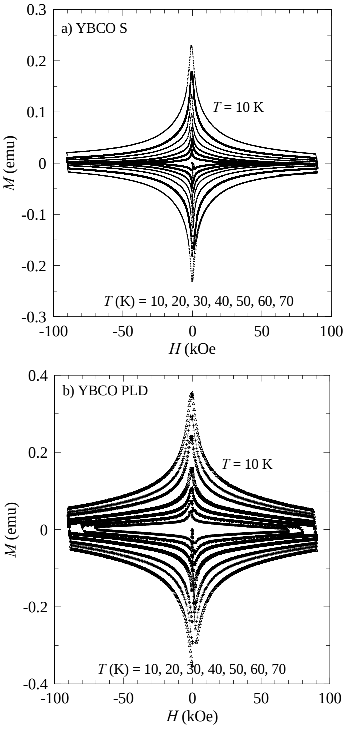

Fig. 1. Magnetization curves of YBCO films obtained by dc sputtering (a) and by PLD (b) at different T values between 10 K and 70 K (step of 10 K).

Fig. 1 illustrates characteristic magnetization curves of YBCO S and YBCO PLD, respectively, for T between 10 K and 70 K and the external magnetic field H oriented along the c axis (e. g., perpendicular to the film surface). Due to the fact that when the quenched disorder degree is high the reversible magnetization is very small compared with the irreversible part, the measured magnetic moment M is very close to the irreversible magnetic moment. However, to eliminate the contribution of the magnetic moment of the sample holder (which can become important at high T) it is better to consider the irreversible magnetic moment $M_{\mathrm{irr}} = (M_+ - M_-)/2$, where M_+ and M_- represent the moment measured for increasing and decreasing H, respectively.

The critical current density J_c (affected by thermally activated flux creep) was extracted with the Bean model [5]. For rectangular samples we used the Bean relation for practical units [6],

$$J_c = \frac{40|M_{irr}|}{dLl^2(1 - l/3L)}, \tag{1}$$

where L is the sample length, l - the width, and d - the thickness. The above relation supplies J_c in A/cm^2 if M_{irr} is in emu and all dimensions are in cm. For disk-shaped thin film specimens, the Bean relation for practical units becomes

$$J_c = \frac{|M_{irr}|}{\frac{\pi}{3}10^{-12}dR^3}, \tag{2}$$

where J_c in A/cm^2 is obtained if M_{irr} is in emu, d in Å, and the disk radius R is taken in mm.

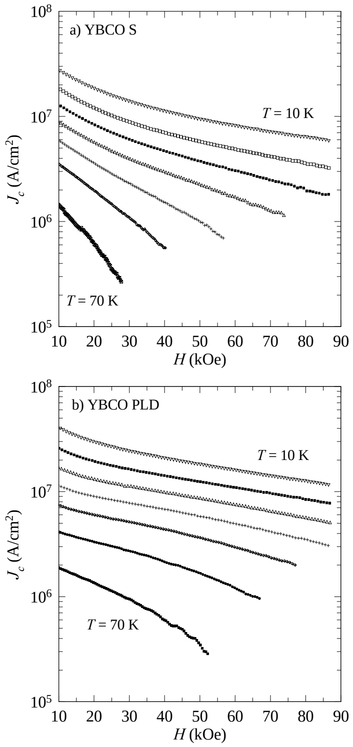

Fig. 2. Critical current density J_c determined from the magnetic hysteresis curves from Fig. 1 for YBCO S (a) and YBCO PLD (b).

In Fig. 2 we plotted the J_c values determined with the above relations vs. H. It is worthy to note that the Bean model [5] can still be applied if H is larger than the magnetic field generated by the induced current. As can be seen, J_c of YBCO PLD overcomes the values resulting for YBCO S in the whole investigated (H, T) domain.

However, the difference is more evident at high H, where the J_c values of YBCO PLD overcome those obtained for YBCO S by a factor >2, depending on T. While both films contain natural growth induced linear defects, which act as effective pinning centers in the low-H domain [7], it appears that in YBCO PLD films stronger pinning centers are born in the deposition process. A stronger vortex pinning at high H in YBCO PLD can be due to the presence of sparse, second phase inclusions (such as Y_2O_3) [8], which necessitates further investigation.

3. Conclusions

The critical current density J_c of optimally doped YBCO films prepared by PLD is usually higher than that obtained for optimally doped YBCO films prepared by dc sputtering, and the difference becomes more evident with increasing magnetic field, which could be explained through the presence of secondary phases (surrounded by dislocations) in YBCO PLD. This makes the PLD, at least in the case of YBCO films, one of the best choices for artificial routes [9-12] to induce strong pinning centers in HTS. The combined pinning effect of natural and artificial defects is expected to lead to competitive J_c values in HTS for practical applications.

Acknowledgments

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