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Effect of Calcium Doping in Low Angle Grain Boundaries of $YBa_2Cu_3O_{7-\delta}$ on Textured Metal Substrates

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Abstract

We report the effect of Ca doping in $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films grown on the Rolling- Assisted, Biaxially Textured Substrates (RABiTS) with the architecture of CeO_2/YSZ/CeO_2/Ni. Critical currents of bilayer and trilayer structures of YBCO/$Y_{0.7}Ca_{0.3}Ba_2Cu_3O_{7-\delta}$ (YCaBCO) as well as undoped YBCO for comparison have been measured in a wide range of temperatures and fields. For 6-8° grain boundaries, 30% Ca-doping in bilayer structure enhances J_C as high as 35 %. The enhancement is larger at low temperatures and at magnetic fields. On the other hand, 30% Ca-doping in trilayer structure reduces J_C as high as 60%. Combined with slightly lower T_C, this indicates that Ca is overdoped in this structure and degrades GBs.

Keywords : YBCO, grain boundaries, calcium doping, critical current

I. Introduction

It has been known that grain boundaries (GBs) in $YBa_2Cu_3O_{7-\delta}$ (YBCO) superconducting thin films are depleted of carriers compared to the bulk and this depletion limits the critical currents in a superconductor. Partial replacement of yttrium in YBCO with Ca has been used to increase GB critical current density (J_c) substantially, but only at temperatures much lower than 77 K. Recently, G. Hammerl *et al.* [1] have reported significantly improved GB behavior at 77 K in YBCO/YCaBCO multilayer structures on 24° [001] tilt GBs. Right after this success, the strong benefit of Ca-doping on 5° [001] tilt GBs in magnetic fields has also been published by G. A. Daniels *et al.* [2].

Encouraged by these results, GB doping with Ca has been conducted in YBCO thin films grown on Rolling-Assited Biaxially Textured Substrate (RABiTS) with 6-8° GBs. Critical currents are measured over a wide range of temperatures and fields. In this paper, we report the effect of Ca doping in low angle GBs.

II. Experimental

The preparation of RABiTS (Ni-plus-buffer-layers -unit) has been described in detail elsewhere [3-6]. Epitaxial cerium oxide buffer layers were deposited on biaxially textured nickel tapes in a vacuum chamber with a typical base pressure before deposition of 2 x 10^{-8} Torr. Annealing of the nickel tape to develop biaxial texture was performed at

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1250°C for 9 min in 2 x 10^{-5} Torr Ar/H_2 (4%) atmosphere as the tape passed along the axis of a heated tantalum tube. Depositing of CeO_2 was accomplished reactively using a flux of ~0.5 Å/s cerium metal from an e-beam heated source. A quartz crystal monitor was used to monitor and control the cerium flux. During depositing, a heater in contact with the tape was held at 400°C. To provide a source of oxygen for CeO_2 formation, a partial pressure of water of 5 x 10^{-6} Torr was established throughout the vacuum chamber using a leak valve. Annealing and deposition were performed sequentially in a single pass as the tape moved at 1.0 m/hr from a payout reel to a take-up reel. The 1 m length tape was then cut into short pieces (5mm x 20 mm) for the deposition of a 300 nm-thick layer of yttria-stabilized zirconium oxide (YSZ) and 20 nm-thick CeO_2 cap layer by RF sputtering while the substrate temperature was maintained at 780 °C in 2 x 10^{-2} Torr of forming gas and 2 x 10^{-6} Torr of water vapor.

Bilayers and trilayers consisting of YBCO and $Y_{0.7}Ca_{0.3}Ba_2Cu_3O_{7-\delta}$ (YCaBCO) as illustrated in Fig. 1 were grown on RABiTS by pulsed laser deposition using both pure YBCO and YCaBCO targets. Samples were grown at 120 mtorr oxygen pressure and a substrate temperature of 790 °C. After one layer was deposited, targets mounted on the multiple target carrousel were switched. After the deposition was completed, the samples were cooled to room temperature at a rate of 7 °C/min, while the O_2 pressure was increased to 550 Torr to ensure full oxygen uptake. The thickness of each sample was determined by Rutherford backscattering spectroscopy (RBS). Samples were then patterned into 1 mm wide bridges, which may contain ~ 20 GBs along the width, by standard photolithography. Low temperature measurements were performed using an 8T superconducting magnet. A standard four-contact configuration was used to evaluate J_c of the samples and J_c was determined using a 1μV/cm criteria. Bilayer and trilayer structure samples including Ca free YBCO were measured after subsequent oxygen annealing at 500 °C for 1 hour. The entire film thickness t including Ca-doped YBCO layer, not just undoped YBCO, was used in calculating J_c.

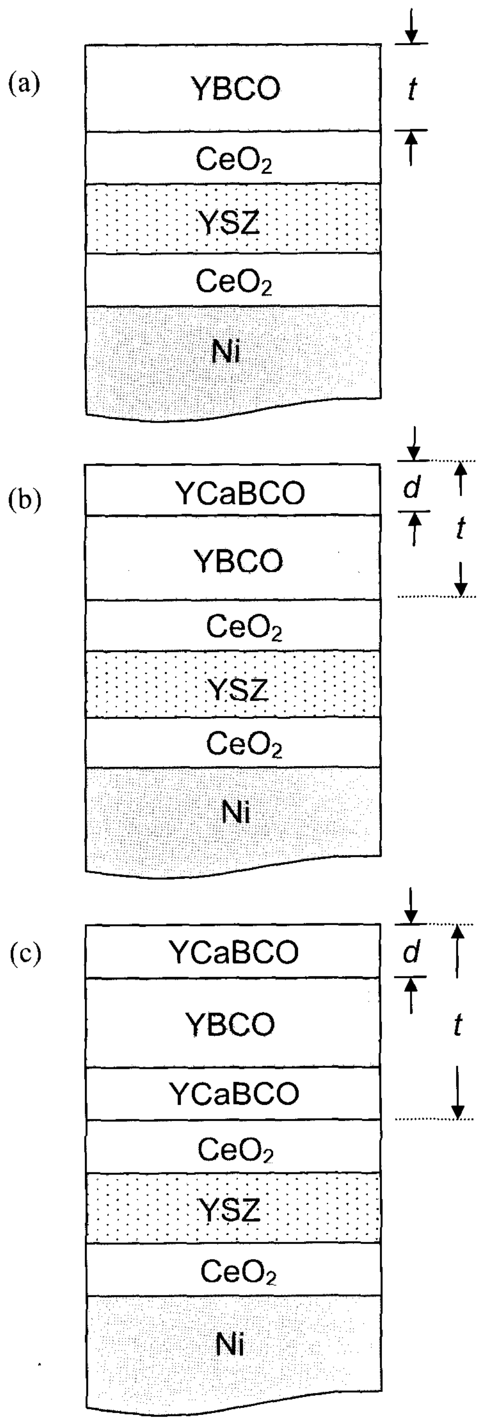

Fig. 1. Illustration of the substrate architecture and the doping heterostructures for (a) undoped YBCO, (b) doping bilayer and (c) doping trilayer.

III. Results and Discussion

30% Ca-doping multiplayer structures were first examined since they have been reported to enhance the J_c substantially for the 24° tilt GBs. A 210 nm thick undoped YBCO and a bilayer consisting of a 165 nm YBCO and a 25 nm-thick YCaBCO on top as illustrated in Fig. 1 (b), and a trilayer consisting of a 165nm YBCO and a 25nm thick YCaBCO on top and bottom as illustrated in Fig. 1(c) were prepared. The transition temperatures (T_{c0}) of the three samples: the undoped and 30% Ca-doped bilayer and trilayer are 90.7 K, 90.9 K and 89.6 K, respectively, as shown in Fig. 2, indicating that superconducting grains remain to be nearly optimally doped in a bilayer structure, while superconducting grains seem to be slightly overdoped by calcium doping in a trilayer structure. Fig. 3 shows the temperature dependences of J_c for the same three samples. The 30 % bilayer doping does not show a significant effect at 77 K, but an obvious trend of J_c increase with Ca-doping is observed at lower temperature regions. Without applied magnetic field, the J_c enhancement by Ca-doping on bilayer structure is 18% and 35% at 70 K and 40 K, respectively. This result is consistent with the earlier works of Daniels *et al.* [2] and Berenov *et al.* [7]. On the other hand, Ca-doping in trilayer structure reduces J_C substantially at whole temperature regions. Combined with the T_C lower than those of undoped and bilayer, this result indicates that trilayer structure is Ca-overdoped and overdoping with Ca degrades GBs. Fig. 4 shows the magnetic field dependence of J_c for the same samples at 20 K, 40 K and 70 K, respectively. Interestingly the undoped YBCO and the Ca-doped samples show nearly the same field dependence of J_c at each temperature, indicating that GBs in YBCO on RABiTS remain as weak links even after Ca is added into GBs. The Ca-doping just shifts the J_c values to higher values at each field. Ca-doping in bilayer structure enhances J_C at magnetic fields up to 5 T. The J_C enhancement is 18% - 35% and is larger in magnetic fields than at zero field. On the other hand, Ca-doping in trilayer structure reduces J_C at fields up to 60%. Again J_C

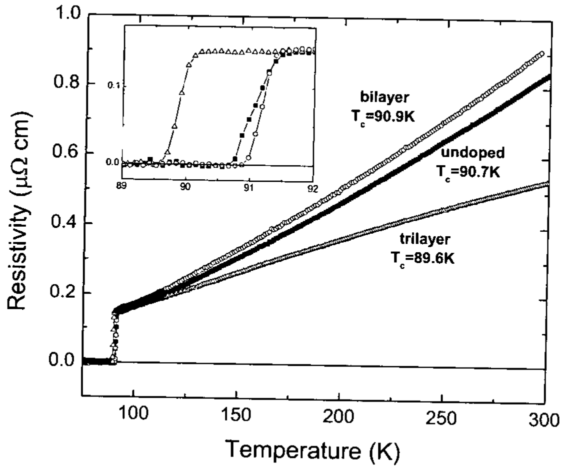

Fig. 2. R-T measurement of undoped YBCO, 30% doped bilayer and trilayer structures. Inset magnifies the low temperature region near the transition temperature. The transition temperature of undoped YBCO, bilayer and trilayer are 90.7K, 90.9K and 89.6K, respectively.

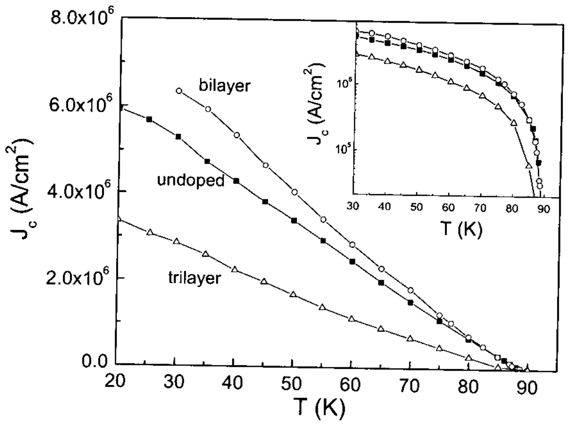

Fig. 3. Temperature dependence of J_c for undoped, 30% Ca-doped bilayer and trilayer at H = 0 T.

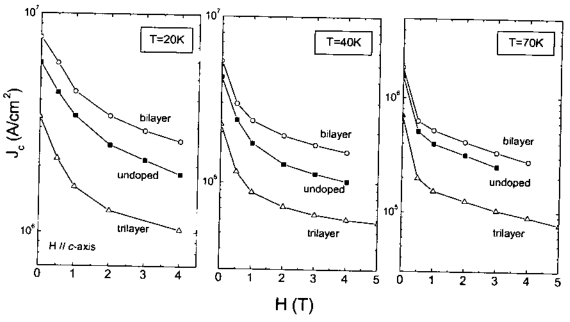

Fig. 4. Magnetic field dependence of J_c for undoped, 30% Ca-doped bilayer and trilayer at T = 20 K, 40 K and 70 K.

reduction in fields is lager than at zero field.

These results show that Ca-doping has a strong benefit on low angle GBs in the presence of magnetic field. In order to find an optimal doping condition for low angle GBs, investigation on lower Ca-content doping and various doping heterostructures is under way.

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