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Enhancement of Critical Current Density in the ($YBa_2Cu_3O_{7-\delta}/Y_2O_3$) × N Multilayered Films

Tran Hai Duc*, Duong Thi Thanh Nhan, Nguyen Huy Sinh

VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

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Abstract: The enhancement of critical current density (J_c) in the ($YBa_2Cu_3O_{7-\delta}$ (YBCO)/Y_2O_3) × N multilayered films was reported. The (YBCO/Y_2O_3) × N multilayered films in which N was varied from 0 to 10 were prepared by using the pulsed laser deposition (PLD) technique. Magnetization data measured at 65 K showed that J_c of the (YBCO/Y_2O_3) × N multilayered films was enhanced in comparison with that of the pure YBCO film. More interestingly, the J_c enhancement was obtained to increase at small values of N, reach the maximum at N = 5, then decrease with increasing N to 10. The J_c enhancements in the (YBCO/Y_2O_3) × N multilayered films with N ≤ 5 were attributed to the increases in the number of single YBCO layers. The microstructure degradation in the (YBCO/Y_2O_3) × N multilayered films with N > 5 was likely to be reason for the decreases in their J_c, which was confirmed by using the scanning electron microscopy (SEM) images.

Keywords: YBCO, critical current density J_c, multilayered films.

1. Introduction

In the family of Rare-earth (RE) superconductors, especially $REBa_2Cu_3O_{7-\delta}$ (REBCO), YBCO was the first materials to be discovered that has been devoted interesting properties for researches [1-5]. Significant efforts have been devoted to YBCO that aimed to its application as the HTS cables require them to process high critical current density (J_c) in higher applied fields. To achieve that purpose, the two major methods have been developed: (i) creating artificial pinning centers (APCs) with the sizes are comparable to the coherence of YBCO, and (ii) inserting non-superconducting layers to divide the YBCO film into several single YBCO thin films. The former was performed by directly mixing the non-superconducting phase such as $BaSnO_3$ (BSO), $BaZnO_3$ (BZO), $BaNb_2O_6$ (BNO)… to YBCO [6]. The latter was carried out by alternately depositing YBCO and non-superconducting phases such as CeO_2, Y_2BaCuO_5 (Y211)…. [7,8]. The completed structure of the films was obtained by repeating the layering process.

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[*] Corresponding author. Tel.: 84-985310900
Email: dhtran@hus.edu.vn

The researches of multilayered processes, however, were mainly focused on the enhancements of J_c. The behavior of numbers of non-superconducting phase on J_c was not clearly studied. In this paper, the enhancements of J_c in the (YBCO/Y_2O_3) × N multilayered films we1e reported. The Y_2O_3 was selected as a proper non-superconducting phase since it had been shown a small lattice mismatch *(0.6%)* and being chemically stable with the YBCO phase [9]. The value of N was varied from 0 to 10 in order to find the optimum N providing the highest enhancement of J_c in the YBCO films.

2. Experiment

The high quality YBCO and (YBCO/Y_2O_3) × N multilayered films were deposited on the $SrTiO_3$ (STO) substrates by using the PLD technique. The 248 nm KrF excimer laser operated at an energy of 250 mJ and a repetition rate of 8 Hz was applied to ablate the target surfaces. The substrates were heated at 800^{o}C and distanced 4 cm from the targets. The depositions of all the films were carried out in the ambient gas of oxygen at a pressure of 200 mTorr. After that, all of the films were in-situ annealed in oxygen at a pressure of 500 Torr for 1 hour, then freely cooled to room temperature.

The crystalline structure of the films and especially the peaks of Y_2O_3 second-phase were analyzed by using the X-ray diffraction (XRD) technique. The surface morphology of the films was examined by using the scanning electron microscopy (SEM) images. The number of Y_2O_3 layers inside the YBCO films was found by using the cross-sectional SEM images. The J_c results were deduced from the magnetization curves measured by using the MPMS XL – 5 systems, in which the field was applied perpendicular to the film surfaces.

3. Results and discussion

The XRD patterns for the single YBCO and the YBCO/Y_2O_3 multilayered films are presented in Fig. 1.

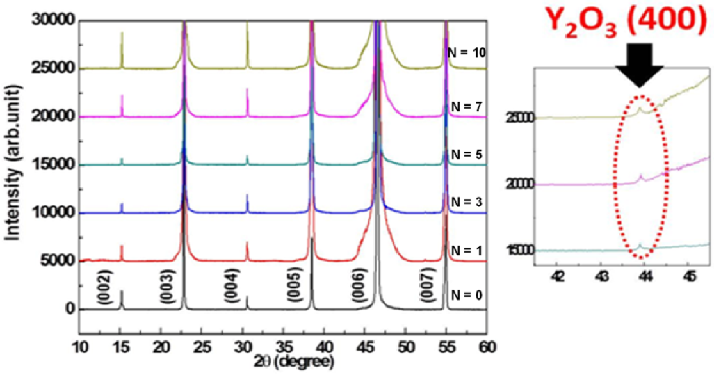

Figure 1. X-ray diffraction patterns of the YBCO single and YBCO/Y_2O_3 multilayered films. The c-axis oriented and a-axis oriented properties of the YBCO and Y_2O_3 phases, respectively, were investigated. Symbol N indicated the number of Y_2O_3 layers.

The dominant (00*l*) peaks (where *l* ranges from 1 to 7) of the YBCO phase suggested that all of the films were *c*-axis oriented. The Y_2O_3 (400) peak was observed only in the Y_2O_3/YBCO multilayered films which indicated the addition of Y_2O_3 layers. Moreover, the intensity of the Y_2O_3 (400) peaks was found to be increased with increasing numbers of Y_2O_3 layers. The structural characterization of the YBCO films carried out by using the cross sectional SEM images revealed that the formation of Y_2O_3 inside the YBCO phase.

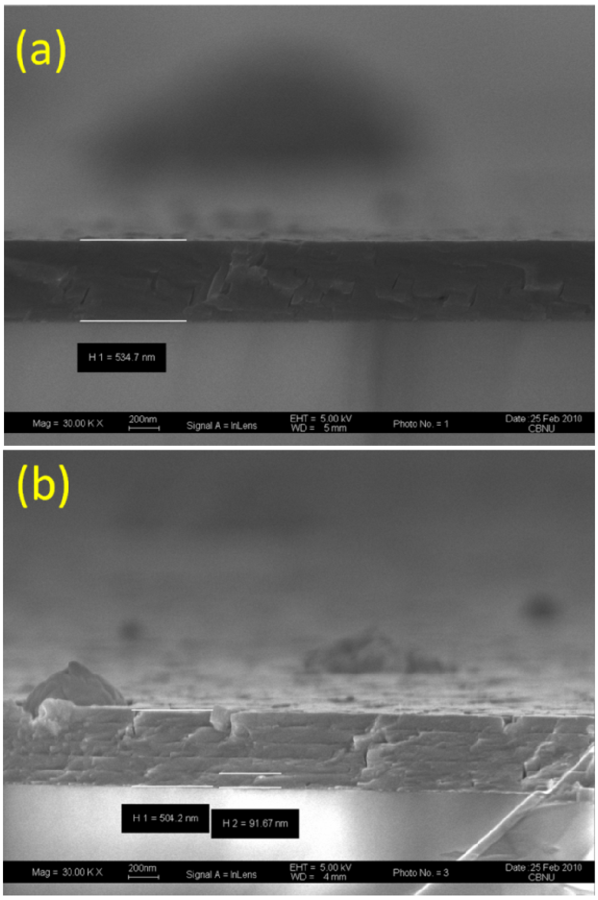

Figure 2. Cross-sectional SEM images of (a) the YBCO single and (b) YBCO/Y_2O_3 multilayered films. The 5 Y_2O_3 layers were observed to uniformly distribute inside the YBCO film.

Fig. 2 (a) showed the cross section of the pure YBCO film. It could be seen that the film were highly c-axis oriented evidenced by a dense layer and a relatively smooth film surface. The film thickness was estimated to be ~ 534 nm, which was compared to be lower than the thickness of ~ 600 nm for growth of the *a*-axis oriented grains [9]. Fig. 2 (b) indicated the Y_2O_3 layers uniformly separated inside the YBCO film with the thickness of each YBCO single layer was approximately 91 nm. Though Y_2O_3 layers were found to be difficult to resolve at these magnifications, these cross sectional SEM images clearly presented the separation between the YBCO single layers. As mentioned in the experiment part, the multilayered structure was obtained by alternatively ablating the two targets or YBCO and Y_2O_3. The smoothness of the Y_2O_3/YBCO film surface with 5 Y_2O_3 layers was also observed to slightly reduce. The big particulates on the Y_2O_3/YBCO film surface were identified to be Cu or Ba-rich phases – the typical property of PLD- films [10].

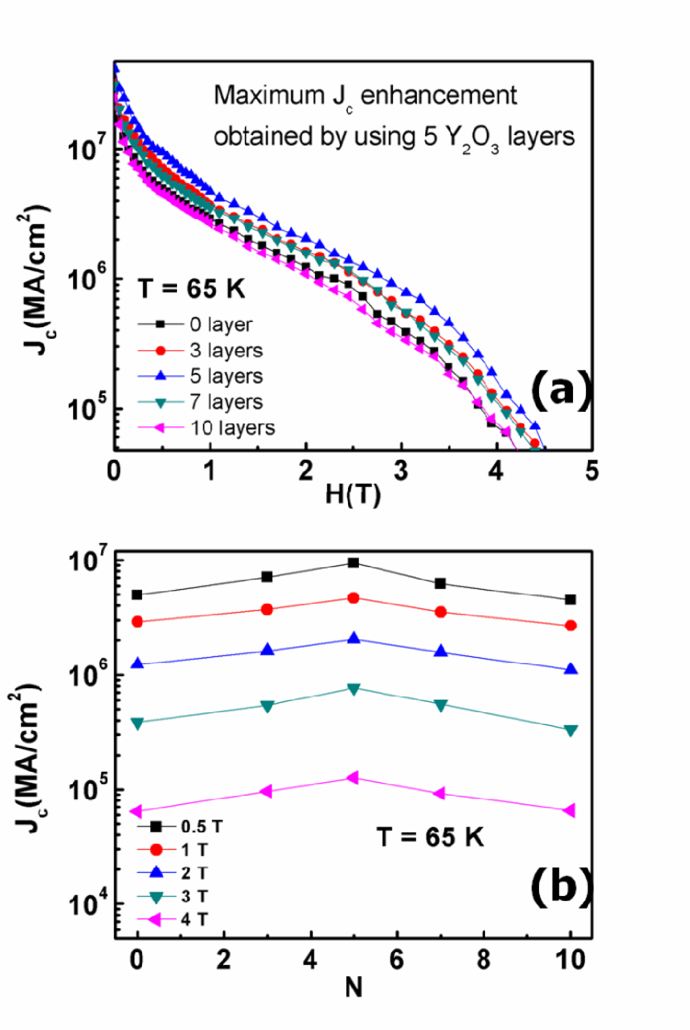

Figure 3. (a) J_c results of the YBCO single and YBCO/Y_2O_3 multilayered films measured at 65 K. (b) The J_c enhancements were obtained in the YBCO/Y_2O_3 multilayered films with the maximum value achieved for the using of 5 Y_2O_3 layers.

The field dependence of J_c of the YBCO and Y_2O_3/YBCO films was investigated. The J_c values were estimated by applying the simplified Bean model, $J_c = 20\Delta M/[b(1-b/3a)]$ [11], where ΔM is the difference in the magnetization per unit volume, a and b are the dimensions of the rectangular samples. A general decrease in the J_c with increasing the applied filed was observed. The J_c values were observed to be highest of ~ 3×10^7 A/cm^2 at self-field and decreased with increasing the applied fields. The self-field J_c of the YBCO and Y_2O_3/YBCO films were compared to be similar, which was reasonable due to the fact that the artificial pinning center (APCs) induced by the addition of Y_2O_3

effectively worked in the applied field only. That idea was examined by analyzing the in-field J_c at different applied fields as shown in Fig. 3 (b). The addition of Y_2O_3 was found to generate the J_c enhancements for N ≤ 5. The possible reason for that might be attributed to the following: the architecture of YBCO/Y_2O_3 × N films was prepared to reduce the formation of microstructural defects including porosity, voids, or the a-axis oriented grains those occurred in thick REBCO films. The interfaces between Y_2O_3 and YBCO served as templates for the growth of subsequent high-quality REBCO layers. It has been well-known that the microstructure evolution at the surface of REBCO thick film was significantly different from that of a thinner one [9], and the REBCO films became rougher with increasing the film thickness. By inserting the Y_2O_3 layers between the YBCO layers, such phenomena were expected to be reduced, and J_c*'s* were enhanced consequently.

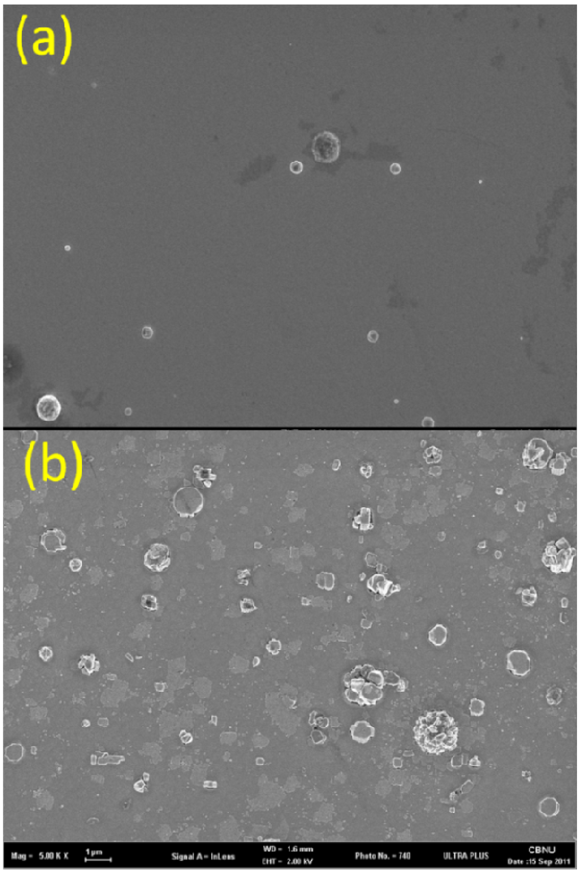

Figure 4. Surface morphologies of (a) the YBCO single and (b) YBCO/Y_2O_3 × 10 multilayered films. The a-axis oriented grains were grown on the surface of YBCO/Y_2O_3 × 10 multilayered films which was attributed to the decreases in J_c enhancement as shown in Fig. 3.

Contrary to the enhanced J_c performances were observed for N ≤ 5, the decreases in J_c with further increasing N from 5 to 10 were exhibited. The results suggested that another mechanism might occur. It has been widely studied that the superconducting and microstructural properties of REBCO films are closely correlated [9]. The surface morphology of the YBCO single and YBCO/Y_2O_3 × N films was examined as presented in Fig. 4. Strikingly, the YBCO single film exhibited a relatively smooth surface (Fig. 4(a)) with only few droplets (or outhgrowths) which were typical for the PLD- films. The observation confirmed that the YBCO single film was highly c-axis oriented as revealed in Fig. 1. By the addition of 10 Y_2O_3 layers (Fig. 4(b)), the smoothness of the film surface was reduced by the formation of the rectangular shapes which were identified to be the a-axis oriented grains. The YBCO/Y_2O_3 × N films with N > 5 were then concluded to be a-axis oriented. The degradation in J_c in the *a*-axis oriented YBCO films was probably explained by using the electronic structure of YBCO. The YBCO unit cell consisted of the two perovskite-structures sandwiched by the Y element. The two CuO_2 superconducting planes were alternated by two BaO insulating planes. The four layers were located parallel to the (*ab*) plane of the perfectly/or highly *c*-axis oriented films which provided the largest opportunity for the horizontally applied currents to flow the CuO_2 planes. If the films were *a*-axis oriented, the flowing of mentioned current might be blocked at BaO planes which led to the degraded J_c's. The further J_c enhancements in the YBCO/Y_2O_3 × N films with N > 5 might be achieved by reducing or avoiding the formation of the observed *a*-axis oriented grains.

4. Conclusions

The YBCO single and YBCO/Y_2O_3 × N multilayered films were successfully fabricated by using the pulsed laser deposition (PLD) technique. The values of N were varied from 1 to 10 to systematically study the effect of N on the field performance of J_c in these YBCO films. Magnetization results measured at 65 K revealed two different effects depending on N. The J_c was enhanced by using small values of N, reach the maximum at N = 5, then decrease with increasing N to 10. Two possible reasons for them were provided. The J_c enhancements in (YBCO/Y_2O_3) × N multilayered films were attributed to the increase in the number of YBCO single layers, in which the formations of microstructural defects such as porosity, voids, or the a-axis oriented grains were eased. These formations, however, were found to remain in the (YBCO/Y_2O_3) × N multilayered films with N > 5 which possibly blocked the super-current flowing along the (*ab*) planes of the films.

5. References

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