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Full Length Article

A comparison of the influence of CeO_2 and In doped CeO_2 interlayer on the properties of the YGBCO/interlayer/YGBCO tri-layer films deposited by pulsed laser deposition

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ABSTRACT

High critical current (I_c) has long been proved important to $REBa_2Cu_3O_{7-\delta}$ (REBCO or RE123) superconductor for the practical applications. To achieve high I_c values, the primary way is to increase the thickness of superconducting layer and to enhance high critical current density (J_c). However, J_c drops precipitously with increasing the thickness of the films. This phenomenon is called the thickness effect, which can be effectively inhibited by fabricating superconductor/interlayer/superconductor tri-layer structure. In this study, a series of YGBCO/CeO_2/YGBCO and YGBCO/In doped CeO_2 (CeO_2 + In)/YGBCO tri-layer films with different interlayer thickness were fabricated. The microstructure, surface morphology and superconducting property of these samples were measured. It was found that all the tri-layer films had pure c-axis orientation. When using CeO_2 film as an interlayer, the two YGBCO layers in the tri-layer films were almost completely isolated, resulting in the low I_c values, which were equivalent to the I_c of a single YGBCO layer. While using CeO_2 + In film as an interlayer, the I_c values of all the YGBCO/CeO_2 + In/YGBCO trilayers were almost double the I_c of a single YGBCO layer, and the I_c values of the trilayers firstly slow increased and then decreased with increasing the thickness of CeO_2 + In interlayer. Under the optimal experimental parameters, the I_c value was much higher than that of the a double YGBCO layer without interlayer. The thickness effect of superconducting layer can be effectively inhibited by inserting CeO_2 + In interlayer with wide thickness range.

1. Introduction

Second generation high temperature superconductor tape (2G HTS tape), also called as coated conductor has been widely studied for high critical current density (J_c) and high superconducting transition temperature (T_c). $REBa_2Cu_3O_{7-\delta}$ (REBCO or RE123) superconductors have always been considered as excellent candidates for various electronic applications, such as electric grids, motors, transportations, magnets and cables [1–4].

High critical current (I_c) is important to REBCO superconductor for the practical applications. Two primary methods for achieving a high critical current (I_c) are to increase the thickness of superconducting layer and to enhance high critical current density (J_c). However, many studies have been reported demonstrate that the critical current density (J_c) drops precipitously with increasing the thickness of the films, which is called "thickness effect" [5,6]. The influence of the thickness on the I_c values have spurred a lot of intensive studies, for instance, the function of temperature (T) and applied magnetic field (H) in the thickness range [7], the addition of nano-defects [8], and the geometrical self-field effect [9]. To date, many progresses have been made to inhibit the thickness effect.

In previous reports, an effective method to inhibit the thickness effect is the preparation of superconductor/interlayer/superconductor tri-layer structure. Yao et al. demonstrated that $SrTiO_3$ (STO) represented a promising interlayer for tri-layer structure, and it can improve the superconducting properties of the films [10]. In addition, Rauch et al draw the conclusion that $NdAlO_3$ was a useful insulating dielectric for electronic applications [11]. Moreover, $LaAlO_3$ was found widely used as the material of interlayer [12].

Cerium oxide (CeO_2) has a fluorite CaF_2 structure with a lattice parameter of 5.41 Å. CeO_2 is widely used as buffer layer because of its better chemical compatibility with substrates [13], high ionic conductivity [14] and small lattice mismatch with YBCO that is 0.52% [15]. Under our experimental condition, CeO_2 buffer layer has

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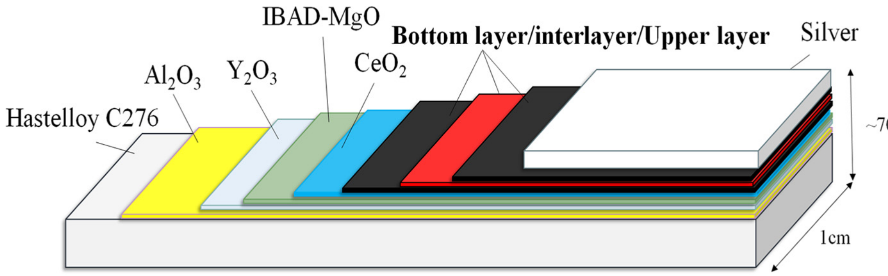

Fig. 1. Sketch of the basic structure of the samples.

properties of strong c-axis orientation and smooth surface by optimizing process parameters. With these excellent performances, CeO_2 represents a promising candidate for the interlayer.

In this study, a series of YGBCO/CeO_2/YGBCO tri-layer films and YGBCO/In doped CeO_2 (CeO_2 + In)/YGBCO tri-layer films with a range of thickness were prepared symmetrically by PLD on CeO_2 buffered IBAD-MgO substrates. The mechanism of the interlayer that affected the superconducting properties of the samples was discussed. To further investigate the influence of the interlayer on the samples' superconducting properties, we also focus on the samples by the perspective of the surface morphology and microstructure.

2. Experimental details

As shown in Fig. 1, the CeO_2/IBAD-MgO/Y_2O_3/Al_2O_3/Hastelloy C276 substrates were used for the deposition of all YGBCO films. YGBCO/interlayer/YGBCO trilayers were done by multi-target reel-to-reel PLD system in this study. As previously reported in detail [16], this system consists of a reel-to-reel PLD chamber with a helix tap handling system (PVD Products Inc.), a KrF excimer laser (LPX220) with the laser beam incident angle of 45°. The CeO_2 buffer layer had a sharp {0 0 1} cube texture from X-ray diffraction (XRD) patterns, and the full-width-at-half-maximum (FWHM) value of typical X-ray ω and φ scans were 1.84° and 4.17°, respectively. By AFM scanning, the root mean square (RMS) roughness was < 2 nm over a 1 μm × 1μm scan area, indicating that the CeO_2 buffer layer had a very smooth surface. Therefore, the high-quality CeO_2 buffer layer provided an excellent epitaxial growth template for the subsequent deposition of YGBCO/interlayer/YGBCO tri-layer films.

In this study, the YGBCO/CeO_2/YGBCO tri-layer structure consisted of the bottom and upper YGBCO layer with the same thickness, and the interlayer of CeO_2 or CeO_2 + In layer with the thickness ranging from 10 nm to 80 nm. A multi-step deposition method was used to deposit the tri-layer structure. The upper and bottom YGBCO layer prepared under the same conditions. The thickness of a single YGBCO layer is 150 nm. As displayed in Fig. 2, the In wires were mixed with CeO_2 target to obtain CeO_2 + In targets, then the CeO_2 + In interlayer was generated by PLD. For comparison, a single and double YGBCO layer without interlayer were deposited under the same condition with the upper YGBCO layer deposition. After the superconducting films were deposited, a silver layer was deposited by the magnetron sputtering as a protection layer. Then, the YGBCO films were annealed in flowing O_2 gas at 500 °C for 4 h.

The texture and structure of the films were analyzed by the X-ray diffraction (XRD) system, utilizing the D8 Discover with general area detector diffraction system (Bruker Advanced X-ray Solutions Inc.). Meanwhile, the Cu Kα radiation ran at 40 mA and 40 kV. The surface morphology and roughness of the films were investigated using atomic force microscopy (AFM, BioScope, Veeco Instruments Inc.).

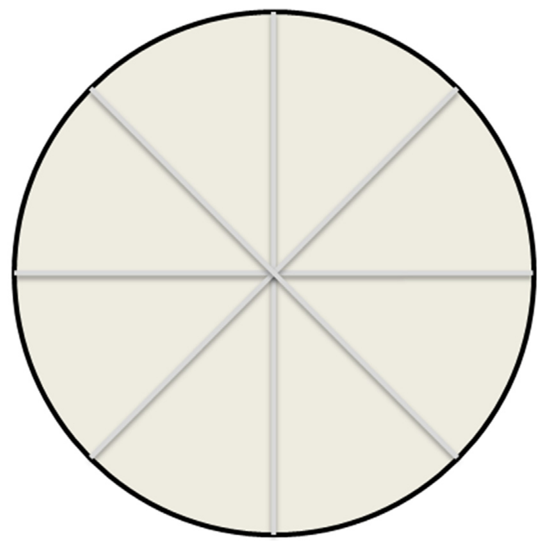

Fig. 2. Schematic diagram of CeO_2 target doped by In wire.

3. Results and discussion

3.1. YGBCO/CeO_2/YGBCO trilayers

The YGBCO/CeO_2/YGBCO tri-layer films were deposited by the multi-step PLD method. To evaluate the superconducting property of the YGBCO/CeO_2/YGBCO tri-layer films, the self-field I_c values were measured in the liquid nitrogen (77 K) by DC four-probe method with a criterion of 1 μV/cm. As shown in Fig. 3, the self-field I_c values of the

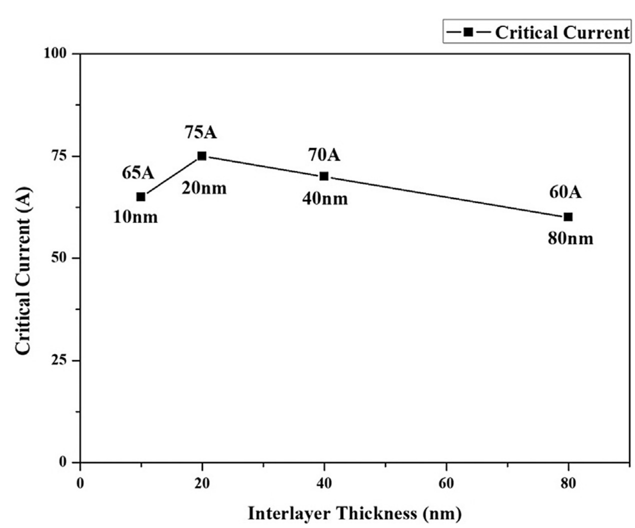

Fig. 3. Self-field I_c values of YGBCO/CeO_2/YGBCO trilayers with the thickness of CeO_2 interlayer ranging from 10 nm to 80 nm.