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Effect of Hf addition on critical current density of (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ thin films prepared by trifluoroacetate metal organic deposition

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ABSTRACT

The critical current density (J_c) performance of YBCO coated conductors (CCs) under magnetic field has become a considerable limitation for its commercial application in recent years. It is well known that the proper amount of element doping into the CCs is a convenient method to increase flux pinning and then to enhance the J_c. In the present work, we firstly introduce the co-doping of Eu and Hf and study the effect on the performance of $YBa_2Cu_{3.6}O_{7-\delta}$ thin films. Three types of high temperature superconducting thin films, i.e., $YBa_2Cu_{3.6}O_{7-\delta}$, (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ and Hf doped (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ were prepared on the oxide buffered metallic substrates by using trifluoroacetate metal organic deposition (TFA-MOD). The component and structure of the as-prepared samples were characterized by X-ray diffraction (XRD), scanning electronic microscopy (SEM) and atomic force microscopy (AFM). Superconducting properties were measured with a SQUID magnetometer. It was revealed that the (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ thin films exhibit better out-plane and in-plane texture compared with the pure $YBa_2Cu_{3.6}O_{7-\delta}$ thin film. The J_c of (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ thin film was improved compared with pure YBCO thin film. In case of Hf doping, however, the biaxial texture became worse while the in-field J_c performance was enhanced, implying the increase of flux pinning with proper Hf addition.

1. Introduction

The second-generation high temperature superconducting wires or coated conductors (CCs), based on YBCO thin film technology, have been confronted with a commercialization opportunity [1,2]. However, high critical current density in high magnetic field is still a challenge. Till now several routes have been verified to have enhanced the J_c value successfully, and the primary approach is enhancing the flux pinning properties of CCs [1–10].

As a leading gent, applicable for the deposition of REBCO films, trifluoroacetate metal organic deposition (TFA-MOD), which is a popular method to prepare coated conductors, has been applied widely due to its low cost as well as easy processing of long tapes. In reality, the recent optimization for TFA-MOD to prepare YBCO CCs, has spurred its commercialization [3,4].

Since it is necessary to enhance the flux pinning properties of TFA-MOD processed YBCO films, many research groups have investigated the substitution of Y ions by rare earth element, such as (Y,RE)$Ba_2Cu_3O_{7-\delta}$ (RE = Y, Gd, Sm, etc.) [4–12]. Introduction of secondary phase nanoparticles such as $BaMO_3$ (M = Zr, Hf, Ce) and $YBa_2SnO_{5.5}$ into the YBCO matrix, has also improved the J_c value in high magnetic fields [13–19]. In the present work, we reported the preparation of YBCO thin film doped with Eu and Hf at the same time by TFA-MOD method. We got that J_c value of (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ thin film was obviously improved than that of the YBCO thin film sample without doping. Then, in order to further enhance its superconducting performance under magnetic field, (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ films with Hf addition were fabricated, and the results showed improvement of J_c values under magnetic fields.

2. Experimental

(Y, Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ and $YBa_2Cu_{3.6}O_{7-\delta}$ thin films were prepared by TFA-MOD. Y, Eu, and Cu acetates were dissolved into propionic acid and deionized water, with the atomic ratio of the element Y and Eu equaling to 2:1, Ba acetates were dissolved into trifluoroacetic acid and deionized water, and the solutions were stirred for 2 h at room temperature. Then the as-prepared solution was distilled to get blue glassy residue. For further purification, we

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dissolved it into methanol to repeat the distillation process described above for three times. Finally, methanol was added into the solutions to adjust the solution concentration to 2.5 mol/L. The solution for the sample of Hf doped (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ was prepared by a similar process, while Hf addition was realized by simply adding of Hf-containing salt into the final solution.

All studied superconducting thin films were prepared on oxide buffered Hastelloy tape, namely Hastelloy/ Al_2O_3/Y_2O_3/ IBAD-MgO/ Epi-MgO/$LaMnO_3$ by using dip coating. The precursor films were put into a high temperature tube furnace for pyrolysis treatment, and followed by a crystallization proccess in flowing atmosphere of humid oxygen and nitrogen gases. Finally, the as-grown thin films were annealed at 450 °C in flowing oxygen for 60 min.

The component and structure were characterized by X-ray diffraction to check the crystallization and growth orientation, and field-emission scanning electronic microscopy (FE-SEM) was employed to check the surface morphologies and thickness. Roughness of surface was observed through atomic force microscopy (AFM). Energy dispersive spectroscopy (EDS) was employed as the preferred method of identification for the presence of the element. The superconducting properties were measured by magnetic property measurement system with a SQUID magnetometer. J_c was calculated using the extended Bean's model from magnetization hysteresis loops as described in the following equation:

$$J_c = \frac{20\Delta M}{a(1-\frac{a}{3b})} \tag{1}$$

where ΔM was the width of the magnetization hysteresis loop, and *a*, *b* ($b > a$) were the width and length of an orthorhombic cross section perpendicular to the applied magnetic field, respectively [9].

3. Results and discussion

The characterization of XRD was performed to get detailed information of crystalline structure and component of all as-prepared thin film samples, as shown in Fig. 1. The derived (00*l*) orientations indicate that all thin films were pure *c*-axis orientation without undesirable phases, and the traceable $BaHfO_3$, or yttria-stabilized hafnia, or $Ba_2Hf_{2-x}Y_xO_6$ phase are hardly detected due to the small amount of Hf addition and their constituent amorphous phase.

Omega and phi scans have been carried out to further examine the out-of-plane and in-plane texture of the films. It was observed in Fig. 1(b) and (c) that the full-width at half maximum (FWHM) of omega scans for the YBCO, (Y,Eu)BCO, and Hf doped (Y,Eu)BCO thin films are 1.72°,1.62° and 1.75°, respectively. The average FWHM of phi scans for the films are 3.43°, 3.14° and 4.06° respectively, indicating good out-plane and in-plane texture of (Y,Eu)BCO. With the increase of Hf amounts, however, the in-plane and out-of-plane texture of (Y,Eu)BCO films become worse.

The surface roughness for the three types of superconducting thin films, i.e., YBCO, (Y,Eu)BCO, and Hf doped (Y,Eu)BCO were investigated by AFM images (within 3 × 3 µm^2 area) as given in Fig. 2. Dense and crack-free surfaces were obtained without any obvious defects on each layer. According to the software evaluation of the surface morphology of each thin film samples, (Y,Eu)BCO film showed smoothest surface morphology and the roughness was 22.9 nm, while the roughness of YBCO and Hf doped (Y,Eu)BCO thin films were 27.1 nm and 24.1 nm, respectively. These results further indicate that the (Y,Eu)BCO film may show a better texture, while the addition of Hf may damage its texture.

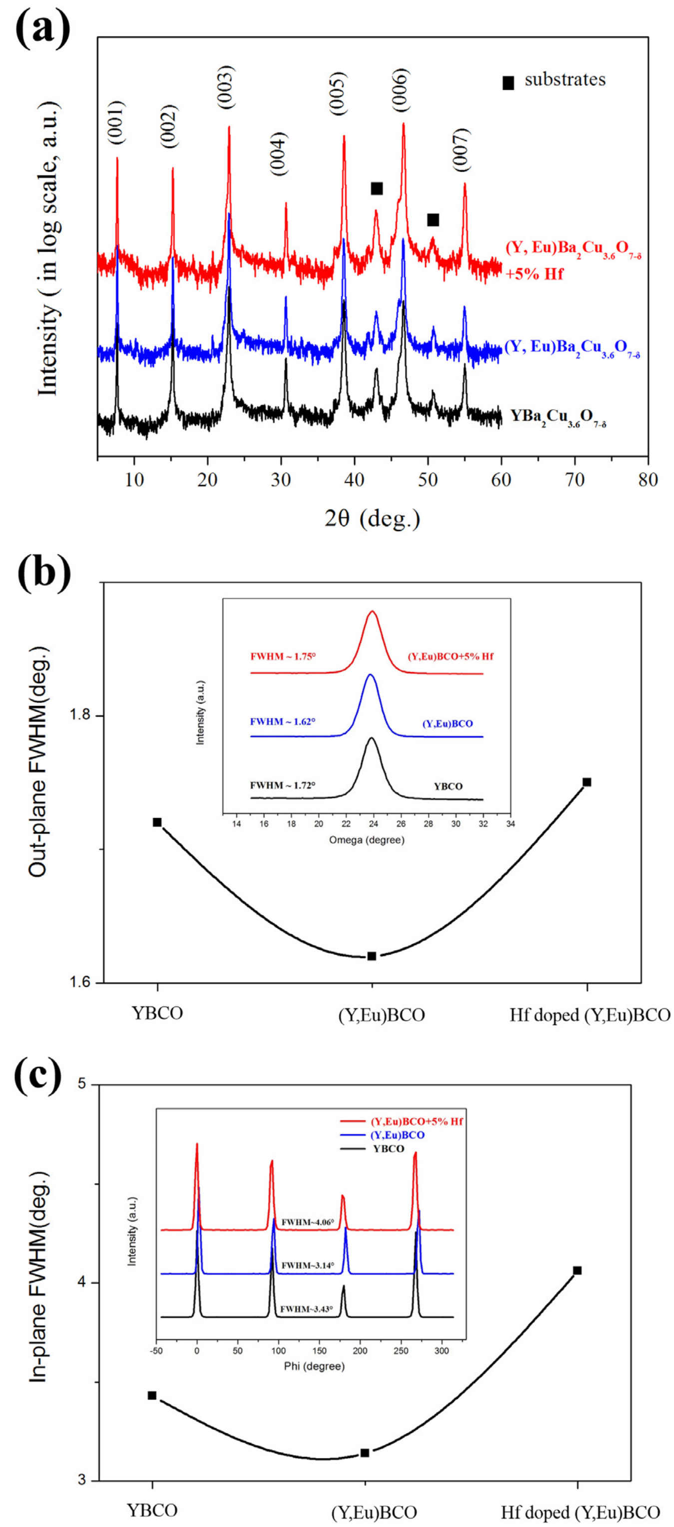

Fig. 1. (a) XRD θ–2θ patterns for $YBa_2Cu_{3.6}O_{7-\delta}$, (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ and Hf doped (Y,Eu)$Ba_2Cu_{3.6}O_{7-\delta}$ thin films, respectively. (b) Omega scans of (005) peak for the studied thin films. (c) Phi scans of (103) peak for the studied thin films.

Fig. 3 shows the SEM morphologies for all studied thin films. It is observed that the (Y,Eu)BCO film show a distinct surface morphology, which is smooth and regular, unlike pure $YBa_2Cu_{3.6}O_{7-\delta}$. In case of Hf addition, the surface of the film becomes rougher and more porous.