Research Article

The Influence of Surface Morphology of Buffer Layer on the Critical Current Density in YBCO Coated Conductors

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Received 28 October 2013; Accepted 7 November 2013

Academic Editor: Danyang Wang

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1 μm -thick $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) films were grown on the Y_2O_3 /yttria stabilized zirconia (YSZ)/ CeO_2 buffer layers with different surface morphologies using direct-current sputtering. The critical current density (J_c) value of YBCO was 1.1 MA/cm^2 when the root mean square surface roughness (R_{rms}) of the buffer layer was 2.5 nm. As the R_{rms} of the buffer layer increased to 15 nm, the J_c decreased to 0.3 MA/cm^2 . X-ray diffraction and scanning electron microscopy showed the strong relevance of the evolution of the structure and surface morphologies of YBCO films with the buffer layer of different R_{rms} . A model was proposed to explain the influence of surface morphology on the superconducting properties of YBCO films.

1. Introduction

Recently, there are more efforts focusing on the fabrication of high performance $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) coated conductors on flexible metallic substrates [1, 2]. The application of 2nd generation coated conductors requires higher current carrying capacity. To reach this goal, a high critical current density (J_c) must be maintained in thick ($>1 \mu\text{m}$) YBCO coatings [3]. Unfortunately, YBCO films deposited on polycrystalline metal substrates showed high angle grain boundaries, leading that the YBCO had a very small critical current [4]. As a result, several methods had been investigated to prepare biaxially aligned templates, such as ion-beam-assisted deposition (IBAD) and rolling assisted biaxially textured substrates (RABiTS) [5, 6]. The RABiTS approach has been proven to be a simple and cost effective manufacturing technology for mass production of coated conductors.

In order to block the interdiffusion of the metal and oxygen, and minimize the lattice mismatch of YBCO and flexible metallic substrates, one or several layer thin films are deposited on the metallic substrates to serve as the buffer layer for the subsequent YBCO films. Typical tri-layer stack of CeO_2 /yttrium stabilized zirconia (YSZ)/ Y_2O_3 is one of the

mostly explored architectures [7]. In this architecture, the Y_2O_3 acts to transfer the biaxial texture from the RABiTS substrate to the YBCO layer; the YSZ layer is used as a barrier to prevent the interdiffusion between oxides and metal substrate; the CeO_2 cap layer on YSZ layer provides good lattice matching and an epitaxial growth template for depositing the YBCO layer. Therefore, buffer layers play a critical role in fabricating high performance coated conductors. So far, enormous efforts had been made toward the manufacture of the biaxial texture of buffer layers on the RABiTS tapes; however, the cap layer had not been paid enough attention [8–10]. In our previous work, we had reported the surface morphology evolution of the CeO_2 films deposited on the YSZ/ Y_2O_3 /Ni-alloy substrates [11, 12]. In this study, we investigated in detail the impact of the surface morphologies of buffer layers on the superconducting properties in YBCO films.

2. Experimental Details

Biaxially textured $\{100\} \langle 100 \rangle$ Ni-5at.%W alloy (NiW) tapes were used in this study, which were supplied from EVICO GmbH, Germany. The full width at half maximum (FWHM)

FIGURE 1: AFM images of different CeO_2 cap layers.

values of out-of-plane and in-plane were about 5.5° and 6° , respectively. The $\text{Y}_2\text{O}_3/\text{YSZ}/\text{CeO}_2$ multilayers with different surface morphologies were deposited on NiW tapes using reel-to-reel direct-current (DC) reactive magnetron sputtering by modulating the substrate temperature from 500°C to

680°C as reported in [12]. The thickness of all CeO_2 cap layers was 40 nm. The subsequent YBCO films were prepared by DC sputtering with the same conditions, which were initially optimized. Detailed conditions were reported elsewhere [3].

FIGURE 2: Typical XRD patterns of $\text{CeO}_2/\text{YSZ}/\text{Y}_2\text{O}_3$ buffer layer (a) θ - 2θ scan, (b) ω -scan of (002) CeO_2 , and (c) ϕ -scan of (111) CeO_2 .

FIGURE 3: XRD θ - 2θ patterns of YBCO films deposited on the buffers of samples from (a) to (e).

FIGURE 4: SEM images of YBCO films deposited on different surface morphologies of buffer layers.

The film structure was measured with Bede X-ray diffraction (XRD) system including θ -2 θ , ω , and ϕ -scan. Atomic force microscopy (AFM, SEIKO SPA300HA microscopy) and scanning electron microscopy (SEM, JSM-5900) were used to characterize the surface morphology and calculate the root mean square surface roughness (R_{rms}). J_c -Scan

system developed by Germany Leipzig University was used to measure the J_c values.

3. Results and Discussion

Figure 1 shows the surface morphologies of the different CeO_2 layers for this series experiments. The R_{rms} values of the

TABLE 1: The R_{rms} of the buffer layers and the values of out-of-plane and in-plane textures of the corresponding YBCO films.

Sample	a	b	c	d	e
R_{rms} of CeO_2	2.5 nm	4.6 nm	5.8 nm	9.5 nm	15.2 nm
$\Delta\omega$ of (002) YBCO	2.37°	2.98°	2.92°	2.97°	3.2°
$\Delta\phi$ of (103) YBCO	4.91°	4.77°	5.07°	4.72°	5.48°

CeO_2 films from (a) to (e) are shown in Table 1. The XRD θ -2 θ scan, ω -scan of CeO_2 (200) peak, and ϕ -scan of CeO_2 (111) plane are shown in Figures 2(a), 2(b), and 2(c), respectively; all the $\text{Y}_2\text{O}_3/\text{YSZ}/\text{CeO}_2$ films are completely c -axis oriented with representative in-plane FWHM value of 5.2° and out-of-plane FWHM value of 3.2° .

The XRD patterns of YBCO films deposited on the buffer samples from (a) to (e) are shown in Figure 3. The deposition time was 20 hours and the typical thickness of YBCO film was $1\ \mu\text{m}$. The 2θ peaks at 33.02° , 33.8° , and 34.9° were indexed as the (001) reflections of CeO_2 , Y_2O_3 , and YSZ, respectively. Weak NiO and NiWO_4 reflections were observed at the 2θ angles of 19.28° , 37.26° , and 43.29° . All of the patterns indicated pure c -axis orientation except for the sample (e), which had a small amount of a -axis grains. The out-of-plane and in-plane textures of YBCO films deposited on samples from (a) to (e) are documented in Table 1. With the exception of the YBCO deposited on sample (e), all the out-of-plane FWHM values of YBCO films were smaller than 3° , demonstrating good out-of-plane alignments. The FWHM values of sample (e) were slightly bigger than others, ascribed to the a -axis grains, and led to the formation of high angle grain boundaries in the YBCO film. The in-plane FWHM values of YBCO films were between 4.7° and 5.5° , indicating no obvious tendency on the in-plane texture when the YBCO films deposited on different buffer layers.

The SEM images of YBCO films deposited on different surface morphologies of CeO_2 cap layers are shown in Figure 4, which corresponded with (a) to (e) of Figure 1, respectively. Figure 4(a) showed the relative flattest surface morphology with typical small holes attributed to the rich yttrium in YBCO films [13]. As the R_{rms} of the buffer layers increased, the holes on the surface of the YBCO films became bigger, as observed in Figures 4(b) and 4(c). As the R_{rms} of the buffer layers increased more than 10 nm, the needle-like a -axis particles of YBCO films were distributed on the surface of YBCO film shown in Figures 4(d) and 4(e).

The relationship between the J_c of corresponding YBCO films is sketched in Figure 5. The J_c of YBCO deposited on the buffer of sample (a) was $1.1\ \text{MA}/\text{cm}^2$. The YBCO deposited on samples (b)–(d) showed J_c values of $0.9\ \text{MA}/\text{cm}^2$, $0.8\ \text{MA}/\text{cm}^2$, and $0.5\ \text{MA}/\text{cm}^2$, respectively. As the R_{rms} of the buffer layers increased to 15 nm, the J_c value of YBCO films continuously decreased to $0.3\ \text{MA}/\text{cm}^2$, revealing the strong relevance between the superconducting properties and the surface morphology.

FIGURE 5: The relationship between the J_c of YBCO films and surface morphologies of CeO_2 layers.

In order to study the mechanism of the effect of the buffers' surface on the performance of YBCO films, the corresponding line profiles of CeO_2 films of samples (a) and (e) were plotted in Figures 6(a) and 6(b), respectively. As shown in Figure 6, the grain height was in the range of $-50\ \text{nm}$ – $50\ \text{nm}$, and the gap between in grain boundaries of sample (a) was much smaller than that of sample (e). In the sputter process, the sputter atoms diffused and nucleated on the substrate surface. However, YBCO is a multielement oxide with different atom radii of Y, Ba, and Cu. For different surface morphologies of CeO_2 films such as sample (e), the gap between grain boundaries was deeper and the grain boundaries area was larger than that of sample (a). If metal atoms diffused from one grain of CeO_2 surface to another, it should overcome the superior potential barrier, while the potential barrier of a Ba atom is bigger than that of Cu and Y atoms. Therefore, if the grain boundary area was large, Ba atoms would be enriched on the grain boundaries, which led to the deviation of YBCO chemical contents, and as observed white particles formed on the surface in Figure 4(e), which was identified as the CuO nonconductive particles. Further demonstrations are necessary for a better understanding by transmission electron microscopy which is ongoing.

4. Conclusions

The influence of surface morphologies of CeO_2 cap layers on the microstructure and critical current density of YBCO films was systematically investigated. YBCO films on the flat surface revealed high quality epitaxial c -axis oriented growth and had much better superconducting properties. As the R_{rms} of the buffer layer increased, the nonconductive particles and a -axis grains on the surface of YBCO were observed, leading to deteriorating the J_c of YBCO films. A model was proposed to understand the phenomena, demonstrating

FIGURE 6: The corresponding line profiles of CeO_2 films (a) of sample (a) and (b) of sample (e).

that the surface morphology of buffer layers had a strong effect on the current carrying capacity of YBCO coated conductors.

Acknowledgments

The authors gratefully acknowledge the support of the National Natural Science Foundation of China under Grant no. 51002024, Sichuan Youth Science and Technology Innovation Research Team Funding (no. 2011JTD0006), and Fundamental Research Funds for the Central Universities (no. ZYGX2012J039 and ZYGX2011Z002) for this work.

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