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Thickness effect of $Gd_2Zr_2O_7$ buffer layer on performance of $YBa_2Cu_3O_{7-\delta}$ coated conductors

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ABSTRACT

Bilayer buffer architecture of $Gd_2Zr_2O_7$ (GZO)/Y_2O_3 was prepared on the biaxially textured tape of Ni–5 at% W (NiW) by reactive sputtering deposition technique. The buffer layer of GZO films were deposited with different thicknesses on Y_2O_3 seeding layer with a given thickness of 20 nm. According to the results of φ-scan, the in-plane FWHMs of GZO films decreased and then reversed with increasing thickness of GZO, which corresponded with the in-plane FWHMs and superconducting properties of $YBa_2Cu_3O_{7-\delta}$ (YBCO) films. Reflection High-Energy Electron Diffraction (RHEED) was carried out to examine the surface texture of GZO films and the deteriorated surface alignment was found for thicker films. The thickness effect of GZO on performance of YBCO is the coupling result of surface texture and blocking effect caused by thickness. With the balance of these two factors, the YBCO/GZO(120 nm)/Y_2O_3/NiW architecture exhibit relatively high performance with the transition temperature T_c of 92 K, a transition width ΔT_c below 1 K, and a critical current density J_c of 0.65 MA/cm^2.

1. Introduction

The second-generation (2G) high temperature superconductors (HTS), which are also known as "coated conductors", have been developing based on the technique of biaxially texture and epitaxial growth of films. Compared with 1G HTS (Bi-2223, Bi-2212), 2G HTS (REBCO, RE = Y, Gd, Sm, etc.) draw more attention due to the excellent performance under high-intensity magnet field and low cost in material. In recent years, 2G HTS has become a hot area in the field of practical superconducting materials. To obtain high quality REBCO superconductors, biaxial texture is highly essential in overcoming the behavior of weak-link in grain boundaries. Three main technologies are used to achieve biaxially textured REBCO films on flexible metallic substrates, including Rolling Assisted Biaxially Textured Substrate (RABiTS) [1,2], Ion Beam Assisted Deposition (IBAD) [3–5] and Inclined Substrate Deposition (ISD) [6]. Among the three, RABiTS is considered to be very promising, on which subsequent buffer layers and REBCO films are epitaxially grown on highly textured substrate. Moreover, chemical solution deposition technique (CSD) for all functional films was proved possible for the low cost preparation [7].

For RABiTS technique, buffer layers, inserted into the HTS/substrate structure, serve as the function layers transferring the texture from substrate to superconducting layer and preventing atom diffusion between them. To avoid these circumstances, the most popular buffer structure in RABiTS route is considered as the tri-layer CeO_2/YSZ/Y_2O_3 [8–10] mainly prepared by physical vapor deposition (PVD). In common, many other kinds of oxide are also used as buffer materials, such as GZO, $La_2Zr_2O_7$ [11] and $Ce_2Y_2O_7$ [12]. GZO is a structure of pyrochlore with a lattice parameter of a = 10.52 Å, which is a relatively low mismatch with YBCO of 3.63% and Ni of 5.37%, respectively. Recently, simplified single GZO [13] and double-layer GZO/Y_2O_3 [14,15] buffers without CeO_2 cap layer were investigated, drawing the conclusions that single GZO buffer layer could be epitaxially grown on NiW substrate and the window would be broaden while introducing Y_2O_3 as seeding layer. Y_2O_3 provides good nucleation surface for GZO film, and the texture of GZO could be improved compared with single GZO buffer in achieving the best quality. In this work, we present the latest effort on study the evolution of texture and surface alignment with the increasing thickness of GZO films.

2. Experimental details

10 milimeter wide highly textured Ni–5 at.% W (NiW) RABiTS tapes supplied by the Evico GmbH [16] were used as the metallic substrates. The cube texture ratio is more than 98% and the in-plane full width at half maximum (FWHM) value is less than 6°. The root mean square surface roughness (RMS) value of NiW

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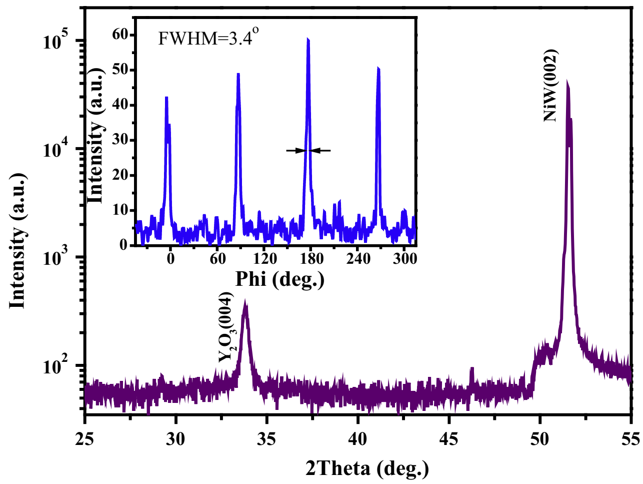

Fig. 1. X-ray θ–2θ scan for the 20 nm thick Y_2O_3 seeding layer on metallic substrate of biaxially texture NiW. The inset shows the result of phi-scan for the same sample.

substrate is less than 5 nm over 5 × 5 μm^2 area. Y_2O_3 and GZO buffer films were prepared in a reel-to-reel reactive magnetron sputtering system. Ar/H_2 served as the sputtering atmosphere to avoid the oxidation of substrate while the reactive gas was H_2O. After the chamber was pumped under 5×10^{-4} Pa, forming gas were introduced and the background pressure was controlled at 2 Pa. Furthermore, YBCO films were prepared by a pulsed-laser-deposition (PLD) system (KrF, λ = 248 nm, f = 5 Hz, E = 2.4 J/cm^2).

Texture and orientation of the films were determined by X-ray diffraction (XRD, PANalytical Empyrean X-ray diffractometer). Morphology of surface was observed through atomic force microscopy (AFM, Nanofirst-3600A). Profile of sample was prepared by focused ion beam technique (FIB, FEI Quanta 200 3D) and then analyzed by scanning electron microscopy (SEM, JEOL JSM-6400 Scanning Microscope). Reflection High-Energy Electron Diffraction (RHEED) was applied to determine the microstructure on the surface of GZO and Y_2O_3 buffer layers. Additional normal-superconducting transition temperature (T_c) and transition width (ΔT_c) were executed by a standard four-probe method in a Quantum Design PPMS-9 system.

3. Results and discussion

Served as the seeding layer, Y_2O_3 was prepared in an optimized P_{H2O} range which is studied in previous work [14]. As one of the most crucial parameters during film preparation, insufficient as well as excessive P_{H2O} lead to the degradation of Y_2O_3 texture because low P_{H2O} cannot afford enough oxygen during the formation process, oppositely if too much P_{H2O} is introduced, the target will be severely oxidized resulting in tremendous changes of sputtering condition, and finally remains the orientation difficult to be controlled. In addition, on the premise of ensuring the function of seeding layer, Y_2O_3 layer was prepared as thin as possible and adequate Y_2O_3 layer was obtained with the thickness of 20 nm.

In Fig. 1, pure c-axis orientation of Y_2O_3 was detected with only Y_2O_3 (004) and NiW (002) peaks visible in the θ–2θ image. X-ray phi scan was applied to verify further texture information of Y_2O_3 layer and the result was given in the inset. Due to the thinness of Y_2O_3 seeding layer, background fluctuates acutely because of the low intensity of characteristic peak. Nevertheless, the in-plane FWHM value reaches 3.4°, indicating great inheritance of biaxial texture from NiW tape.

The surface morphologies of 20 nm thick Y_2O_3 seeding layer and 120 nm thick GZO buffer layer were investigated by AFM images as given in Fig. 2. Within 1 × 1 μm^2 area, Dense and crack-free surface were obtained without any obvious defects on both layers. As the result of very low thickness, Y_2O_3 layer achieves a RMS value of 1.5 nm, revealing significant planarization toward metallic substrate. Compared with Y_2O_3 layer, the RMS value of GZO is 2.5 nm, presenting a slight deterioration because GZO layer gradually transforms from layer growth mode to island growth mode with the increase of thickness, which lead to the emergence of mismatch inside GZO crystal. Anyway, the bilayer buffer architecture of the GZO/Y_2O_3 do promotes the surface quality of bare NiW tape, demonstrating an improvement compared with bare NiW tape.

Cross-SEM observation was implemented on the cross-section in Fig. 3 to check if the buffer layers are homogeneous. The structure is Au/YBCO/GZO/Y_2O_3/NiW, in which the GZO is 120 nm thick. According to the photograph, all boundaries are distinct and smooth without any defects or visible interfacial reaction. In spite of just 20 nm, Y_2O_3 can play an effective part in substrate planarization and offer great nucleating surface for upper buffer architectures, which is proved by the flat plane between Y_2O_3 and NiW.

By means of controlling tape speed, we prepared GZO layers with different thickness of 40 nm, 80 nm, 120 nm, 160 nm and 200 nm on as-deposited Y_2O_3 seeding layer. X-ray phi scans were carried out to investigate the thickness effect on in-plane grain texture of GZO and YBCO layers, as shown in Fig. 4. Increasing the thickness of GZO layer from 40 nm, the FWHM value shows an reduction trend and reaches the lowest FWHM values at the thickness of 120 nm, indicated by GZO (2 2 2) and YBCO (1 0 3) phi-scans

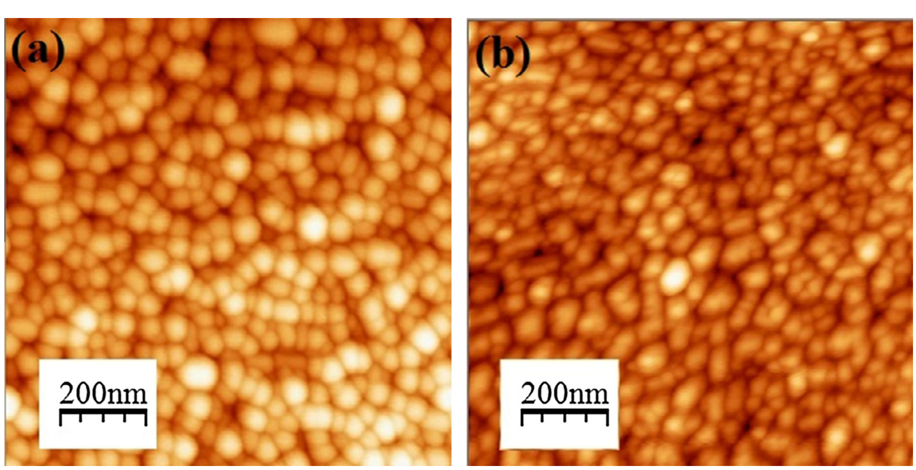

Fig. 2. AFM images for the: (a) 20 nm Y_2O_3 seeding layer on the NiW tape and (b) 120 nm $Gd_2Zr_2O_7$ buffer on Y_2O_3 seeding layer.