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In-plane aligned YBCO film on textured YSZ buffer layer deposited on NiCr alloy tape by laser ablation with only O^+ ion beam assistance

Xin Tang Huang†‡, You Qing Wang†, Qiu Liang Wang† and Qing Ming Chen†

† National Laboratory of Laser Technology, Huazhong University of Science and Technology, Wuhan 430074, People's Republic of China

‡ Department of Physics, Central China Normal University, Wuhan, 430079, People's Republic of China

E-mail: xthuang@phy.ccnu.edu.cn

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Abstract. High critical current density and in-plane aligned $YBa_2Cu_3O_{7-x}$ (YBCO) film on a textured yttria-stabilized zirconia (YSZ) buffer layer deposited on NiCr alloy (Hastelloy c-275) tape by laser ablation with only O^+ ion beam assistance was fabricated. The values of the x-ray phi-scan full width at half-maximum (FWHM) for YSZ(202) and YBCO(103) are 18° and 11°, respectively. The critical current density of YBCO film is 7.9×10^5 A cm^{-2} at liquid nitrogen temperature and zero field, and its critical temperature is 90 K.

For the purpose of electric power and energy storage applications, many researchers have been studying high critical current density YBCO films based on flexible metal materials and their application properties [1–3]. Because of the high-angle grain boundaries in conventional YBCO films leading to weak-link behaviour [4–7], the preparation of YBCO films with *c*-axis oriented normal to the film surface and textured in the *a*–*b*-plane on flexible metal materials becomes the key problem for high quality YBCO films.

In order to control in-plane alignment of YBCO films on Ni-based alloy tapes, Iijima used ion-beam-assisted deposition techniques to produce in-plane aligned intermediate YSZ buffer layer films on NiCr alloy tapes, and then in-plane textured and high critical current density (2.5×10^5 A cm^{-2}) YBCO films were obtained, where the $O^+ + Ar^+$ ion beam was used to assist the film growth of YSZ and the energy of the assisting ion beam was 300 eV [8]. Knierim fabricated in-plane textured YSZ buffer layers on stainless steel tapes with ion beam assistance techniques, where the ion beam used was $Ar^+ + O^+$ and the ion beam was accelerated to about 300 eV also [9]. The important difference between the YSZ films of Iijima and Knierim is the thickness of the YSZ buffer layers. The thickness of the YSZ buffer layer film of Iijima is 0.6 μm and that of Knierim is 2.5 μm. According to the results of Iijima and Knierim, the texture of the YSZ layer was improved by increasing the buffer layer's thickness, and this is in accordance with the growth model proposed by Sonnenberg and Ressler [10, 11]. Wu deposited a YSZ buffer layer on Ni-based alloy tape with only an Ar^+ ion beam whose energy was 250 eV, and then under the same conditions CeO_2 and YBCO films were deposited on the YSZ/NiCr substrates respectively. The critical current density of the YBCO film is 8×10^5 A cm^{-2}. Here the main purpose of depositing the second buffer layer of CeO_2 is to improve the lattice match of CeO_2 (100) with YBCO(110) [12].

Reade and coworkers investigated the differences of YSZ buffer layer microstructures with only O^+ or Ar^+ ion beam assistance in the range of 50 to 200 eV ion beam energies. They concluded that under that condition the YSZ buffer layers deposited with only Ar^+ ion beam assistance have the *c*-axis oriented normal to the film surface and are textured in the *a*–*b* plane. But in the YSZ buffer layers deposited with only O^+ ion beam assistance there is no evidence for alignment of the in-plane crystal axes [13]. They attributed the different effects of the two ions to the differences of inertness, size and mass between oxygen and argon ions. But the authors did not report the further results as the ion beam energy is above 200 eV. Otherwise Bradley *et al* have developed a model to explain the development of preferred orientation in films exposed to low-energy ion beams (<1 keV) during film growth. They base their model on difference in sputtering yields for different orientations rather than reorientation during recrystallization. The development of a textured microstructure is thought to be the result of the higher sputtering yields of all orientations other than the channelling direction [14]. On the bases of the model of Bradley and the above experimental results, we propose that we can further enhance the O^+ ion beam energy above 200 eV and restrain the activity of the O^+ ion beam to obtain in-plane aligned YSZ buffer layers on the metal substrates. Because it is probably further to sputter out YSZ crystallites that have *c*-axis normal to the film surface but are not in-plane textured and let those YSZ crystallites that have *c*-axis orientation normal to the film surface and are aligned in the *a*–*b* plane remain only. If that is right, the energetics and the inertness of the assisting ions are the main factors that effect the in-plane texture microstructures of the deposited YSZ films, not the size and the mass of different assisting ions.

To demonstrate the above idea, in this paper we prepared YSZ buffer layers on NiCr alloy tapes by laser ablation with only O^+ ion beam assistance and then the YBCO films were deposited on the YSZ/NiCr. The energy of the ion beam is enhanced to 500 eV, and a neutralization electrode of electrons is placed in the centre of the ion beam to increase the inertness of the O^+ ions and prevent the active O^+ ions affecting the depositing film surface as the YSZ films are deposited. The concrete conditions of deposited YSZ and YBCO films are indicated in table 1.

Table 1. Deposition parameters for the YSZ and YBCO films.

Film depositing parameters	YSZ film	YBCO film
wavelength of laser (nm)	308	308
energy density of laser (J cm^{-2})	3	3
frequency of laser (Hz)	12	10
background pressure (Pa)	5×10^{-3}	1
source of ion beam	O_2	
current of the ion beam source (A)	6	
energy of ion beam (eV)	500	
current of neutralization (A)	3	
total pressure of film deposition (Pa)	5×10^{-2}	25 (O_2)
distance between substrate and target (cm)	4	4
substrate	NiCr	YSZ/NiCr
substrate temperature (°C)	room temperature	750
thickness of film (μm)	3.0	1.5
angle between the ion beam and the tape's normal direction (°)	54.7	

The x-ray diffraction (XRD) patterns of 2θ and φ scans (202) of YSZ films deposited under the above conditions are shown in figures 1 and 2, respectively. The results indicate that the YSZ film is not only in *c*-axis orientation normal to the film surface, but also in *a*–*b*-plane

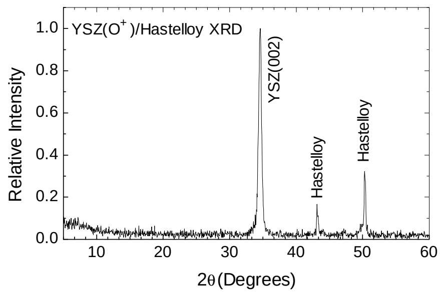

Figure 1. XRD of YSZ/NiCr.

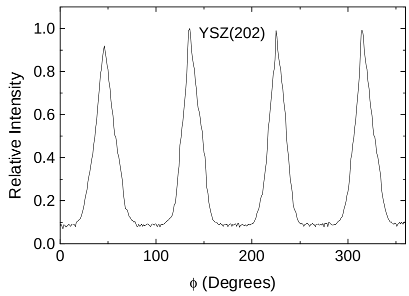

Figure 2. XRD φ scans of YSZ(202).

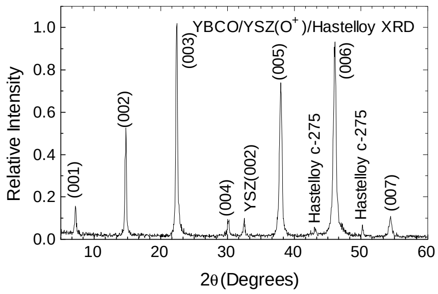

Figure 3. XRD of YBCO/YSZ/NiCr.

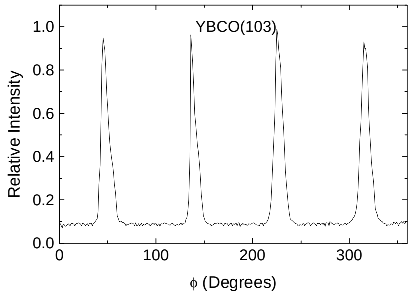

Figure 4. XRD φ scans of YBCO(103).

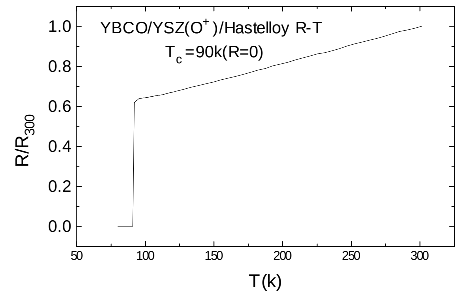

Figure 5. R–T curve of YBCO film.

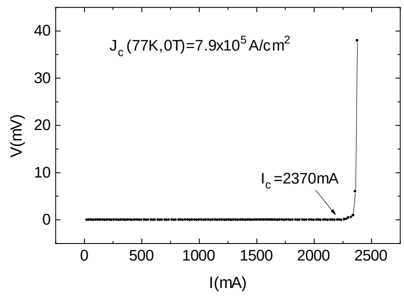

Figure 6. I–V curve of YBCO film.

alignment. The FWHM of the YSZ film in-plane mosaic is 18°. This is in accordance with the above analysis. The XRD patterns of 2θ and φ scans (103) of YBCO film deposited under the above conditions are shown in figures 3 and 4, respectively. They show that the YBCO film is c-axis oriented normal to the film surface and in a–b-plane textured. The FWHM of the YBCO film in-plane mosaic is 11°. The result predicts that the critical current density of the YBCO film can reach $\sim 10^6$ A cm^{-2} [9]. The R–T characteristic curve and the I–V characteristic curve of the YBCO film are measured with a four-point method on laser etched microbridges (1000 μm $\times$ 200 μm $\times$ 1.5 μm), The results are shown in figures 5 and 6. The dc critical current densities (1 μV mm^{-1} criterion) is 7.9×10^5 A cm^{-2} (77 K, 0 T), the critical temperature of the YBCO film is 90 K and the ΔT is $\sim$2 K respectively.

In summary, according to the mechanism of film growth with ion beam assistance, we demonstrated that the energetics and the inertness of the assisting ions are the main factors that affect the in-plane texture microstructures of the deposited YSZ films. A high critical current density and in-plane aligned YBCO film on textured YSZ buffer layer deposited on NiCr alloy tape by laser ablation with only O^+ ion beam assistance was fabricated, where the energy of the O^+ ion beam is enhanced up to 500 eV and a neutralization electrode of electrons is lain in the centre of the ion beam to increase the inertness of O^+ ions and prevent the active O^+ ions affecting the depositing film surface as the YSZ films are deposited. The values of x-ray phi-scan FWHM for YSZ(202) and YBCO(103) films are 18 and 11°, respectively. A critical current density of 7.9×10^5 A cm^{-2} of the YBCO film is obtained at liquid nitrogen temperature and zero field. The critical temperature of the YBCO film is 90 K.

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