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YBCO coated conductor with a single Y_2O_3 buffer layer on biaxially textured Ni and NiW substrates

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***Abstract*-- A study regarding the epitaxial growth of single Y_2O_3 buffer layer on biaxially textured Ni and NiW substrates using pulsed laser deposition is presented. Different deposition conditions were employed and compared in order to obtain good epitaxial Y_2O_3 film, furthermore importantly, to obtain good YBCO superconducting films. Following YBCO film deposited by PLD on the top of Y_2O_3 films have a good structure and superconducting properties. The J_c of YBCO films on Y_2O_3/Ni and Y_2O_3/NiW were 1.0×10^6 A/cm^2 and 1.1×10^6 A/cm^2 at 77K and self-field respectively, which indicated that Y_2O_3 is a suitable candidate as a single buffer layer for the fabrication of YBCO coated conductor.**

1. INTRODUCTION

High temperature superconductor (HTS) coated conductor is multi-layer hetero-epitaxial coating of oxides (one of the multi-layer is $YBa_2Cu_3O_7$) on either a textured substrate or a textured oxide layer deposited on a polycrystalline substrate, and is expected to satisfy the requirements of the practical application of HTS devices operating in liquid nitrogen temperature. In one approach, the HTS films with high critical current densities (J_c) at 77 K have been achieved for epitaxial $YBa_2Cu_3O_7$ (YBCO) films on thermo-mechanically treated biaxially-textured metal substrates with the use of certain multi-layer buffer architecture between the substrate and HTS layer (called RABiTS method)[1,2]. In order to realize coated conductor possessing with a high critical current, the buffer layer architecture which serves as the seed for epitaxial growth of oxide films on metal, diffusion barrier, and the template for epitaxial deposition of superconducting layer, must satisfy a set of strict chemical and mechanical requirements. These objectives have required multi-layer combinations of various oxide buffer layers such as CeO_2/YSZ/CeO_2 or CeO_2/YSZ/Y_2O_3. These multi-layer buffers make the fabrication process of coated conductor complicated and costly. Many efforts on the use of single buffer layer in coated conductor have been done with yttria-stabilized zirconia [3], $La_2Zr_2O_7$ [4], $La_{0.7}Sr_{0.3}MnO_3$ [5], and $LaMnO_3$ [6,7]. Compared to the CeO_2 layer on top of the metal that is prone to crack especially when it gets thicker than several tens of nm and therefore can cause severe reaction between YBCO and metal substrate, which degrades the superconducting properties of the conductor, Y_2O_3 does not have serious cracking problem even when it is relatively thick (several hundred nm)[4]. This result suggests that Y_2O_3 buffer layer may be suitable as a single buffer layer for coated conductor. Some researches [8,9,10] have been done to deposit Y_2O_3 film for the single buffer layer. In this study, we report on the growth of epitaxial (001) Y_2O_3 on a biaxially-textured Ni and Ni – 3 at%W (NiW) substrates, and the properties of YBCO coated conductor with a single Y_2O_3 buffer layer.

2. EXPERIMENTS

Y_2O_3 and YBCO films were deposited using pulsed laser deposition (PLD). A stoichiometric Y_2O_3 and an YBCO ceramic targets of 2-inch diameter were ablated by an exicmer KrF pulsed laser with 248 nm wavelength. Biaxially textured Ni and NiW substrates with the size of about 3×12 mm^2 were attached with a silver paste on a target holder (also the heater) which was directly facing the target at on-axis position . The deposition temperature was measured by a thermocouple located in the heater block. A laser beam was brought to the target surface with an angle of 60° to the normal of target, and target-substrate distance was 65 mm. The size of a laser spot on target was ~ 5×1 mm^2, and the laser pulse energy density on the target was ~ 2 J/cm^2. The target was rotated at 10 rpm, and the laser beam was scanned to achieve about 20×20 mm^2 uniform deposition area. For each batch of deposition, one Ni and one NiW substrate were installed next to each other for comparison.

The X-ray diffraction system of D8 DISCOVER with GADDS (general area detector diffraction solution) from Bruker was used to analyze the orientation of films with XRD θ-2θ scan, ω-scan and ϕ-scan with sample oscillation using a 1/4-circle Eulerian cradle xyz stage. The resistance and transport I_c were measured using a standard four-probe technique without patterning. The voltage contact distance was 4mm, and the $J_c$value was calculated using a 1 μV/cm criterion. The thickness of films was measured using a stylus profilometer.

3. RESULTS AND DISCUSSION

Pure Ni and Ni – 3at % W tapes with biaxial texture manufactured by the standard cold rolling and recrystallization process were provided by Oxford Superconducting Technology. The in-plane and out–of–plane texture of Ni and NiW substrates used in this work were valued by the FWHM (full width at half maximum) of ϕ-scan ($\Delta\phi$) and ω-scan ($\Delta\omega$). The NiW substrates possess sharper biaxial texture with in-plane and out-of-plane textures of $\Delta\phi$ = 7-9° and $\Delta\omega$ = 7-8° as compared with $\Delta\phi$ = 8-10° and $\Delta\omega$ = 8-9° of the Ni substrates. Different deposition conditions of Y_2O_3 film were investigated to find out the optimal deposition condition which leads to the biaxial cube orientation of the Y_2O_3 film on the textured Ni or NiW alloy substrate. In order to obtain high quality Y_2O_3 film, the deposition of Y_2O_3 was separated into three steps. Ar+4%H_2 reducing atmosphere was used for both the heating of the substrate and the deposition of the first part of the Y_2O_3 film to prevent the native oxide on the surface of the metal substrate from influencing the epitaxial relation between the substrate and the growing film. A similar process has been used to deposit CeO_2 on biaxially textured Ni substrate[11]. In reducing atmosphere, the (00L) orientation of Y_2O_3 can be obtained in the wide deposition temperature range of 500-750°C, which is basically due to the good lattice match between Y_2O_3 and Ni (lattice mismatch about 5.7%). Compared to CeO_2 film (lattice mismatch with Ni about 8.8 %) which tends to crack on textured metal when it gets thicker than about 100 nanometer, the Y_2O_3 film which has better lattice match and chemical compatibility with Ni, does not have cracking problems. The images of scanning electron microscope and optical microscope showed no evidence of microcracks in the Y_2O_3 film with the thickness of greater than 0.5μm (Fig.1). After the ϕ-scan and ω-scan analyses, the optimal deposition temperature for the first step was chosen around 650°C. The other deposition parameters were: 200mT Ar+4%H_2, laser energy of 200mJ/pulse, laser repetition rate of 10Hz. The film thickness of this part was about 150nm.

The reducing atmosphere was followed by pumping to the base pressure of the system which was ~8 x 10^{-6}Torr, where the second part of Y_2O_3 film was deposited. At this step, two deposition atmospheres were chosen and compared. One was in 0.1mTorr oxygen atmosphere; another was in vacuum below 8 x 10^{-6}Torr. The other deposition parameters in second step were the same as the first step except the 20 Hz repetition rate of laser used to increase deposition rate. The film thickness of this part was about 280nm. For depositing Y_2O_3 on pure Ni in these two ambiences, the texture of Y_2O_3 film and the superconducting properties of the following YBCO film were better in 0.1m Torr oxygen than in vacuum, but the difference was not much. The similar difference was also reflected by the Y_2O_3 texture on NiW, but this time it was slightly better in vacuum than in 0.1mTorr oxygen, and good biaxially textured Y_2O_3 film on NiW in vacuum could be obtained. However, there was significant difference in the surface morphology and superconducting properties of YBCO films on the Y_2O_3/NiW with the second part of Y_2O_3 deposited in different ambiences. YBCO films on top of Y_2O_3 with the second part of Y_2O_3 deposited in vacuum was much better than that in 0.1mTorr oxygen. Fig. 2 shows. θ - 2θ XRD scans for YBCO/Y_2O_3 films deposited on textured Ni-W substrates. In Fig.2, plot A was the Y_2O_3 deposited in vacuum oxygen at second step, and plot B was the Y_2O_3 deposited in 0.1mTorr at second step. From Fig. 2, it can be seen that the Y_2O_3 and YBCO are c-axis oriented for both samples, but there is a NiO(111) reflection peak of plot B, which indicates the Y_2O_3 buffer layer does not completely obstructe the oxidation of NiW during YBCO deposition. The divergence between the deposition Y_2O_3 on Ni and NiW is due to NiW is easier oxide than pure Ni. Most of the NiO was formed during the YBCO deposition which was carried out at higher oxygen partial pressure.

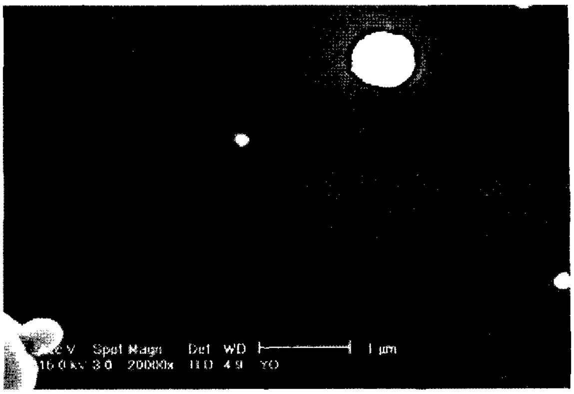


Fig. 1. SEM image of Y_2O_3 film with the thickness of 500 nm on Ni-W.

The third deposition step of Y_2O_3 as a cap layer with thickness of 25nm was done at 0.1 mTorr oxygen atmosphere and at laser repetition rate of 5 Hz for both Ni and NiW in order to achieve final good lattice alignment and smooth surface. Table 1 shows the summary of the deposition conditions used to deposit epitaxial Y_2O_3 film on textured metal substrate and the results of the texture of Y_2O_3 and the superconducting properties of YBCO film.

The YBCO film was deposited in the deposition temperature range of 770~790°C in 200 mTorr oxygen pressure on the Y_2O_3 film. The laser conditions were: energy of 150mJ/pulse and 10 Hz. Following deposition, the YBCO film was quickly cooled to 550°C under deposition pressure, and then kept for 20 min under the

TABLE I.
SUMMARY OF THE DEPOSITIOCONDITION OF Y_2O_3 BUFFER LAYER AND THE RESULTS

Deposition Material	Deposition steps	Deposition atmosphere				Deposition temperature	Energy / pulse	Laser frequency	Thickness
		Ni		NiW					
Y_2O_3	Step 1	200 mTorr $Ar+4\%H_2$		200 mTorr $Ar+4\%H_2$		650°C	200mJ	10Hz	150nm
	Step 2	Vacuum	0.1 mTorr O_2	Vacuum	0.1 mTorr O_2	780°C		20Hz	280nm
	Step 3	0.1 mTorr O_2		0.1 mTorr O_2		780°C		5Hz	25nm

Results	$\Delta\phi$ of Y_2O_3 (°)	9 ~ 10	~ 8	7 ~ 8	9 ~ 10
	J_c of YBCO (MA/cm^2)	~ 0.5	~ 1.0	~ 1.0	~ 0.1

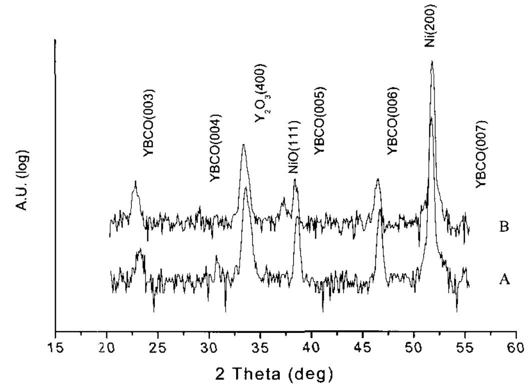


Fig. 2. XRD θ-2θ scans for YBCO/Y_2O_3 films deposited on biaxially-textured NiW substrates. Plot A was the Y_2O_3 deposited in vacuum at second step and plot B was the Y_2O_3 deposited in 0.1 mTorr oxygen at second step.

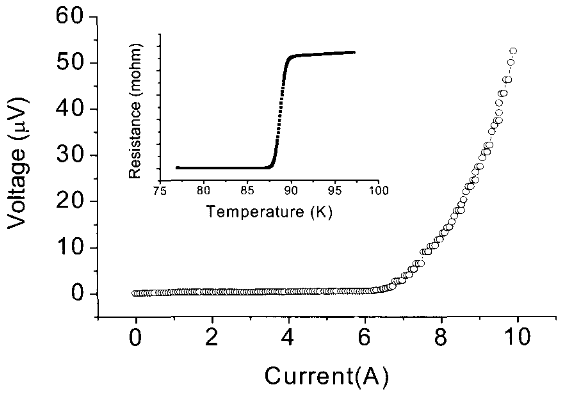


Fig. 3. The I_c and T_c measurements of the best sample of YBCO/Y_2O_3/Ni with the YBCO thickness of 220 nm and width of 3.2 mm.

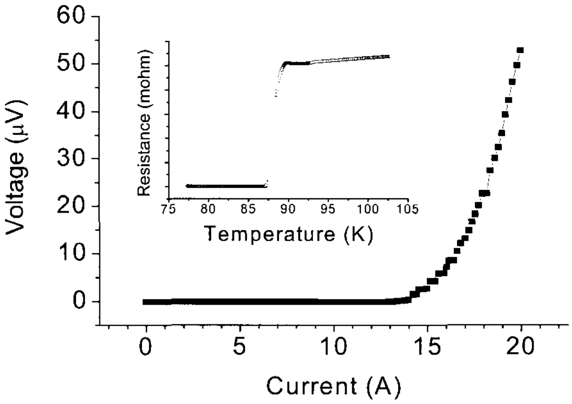
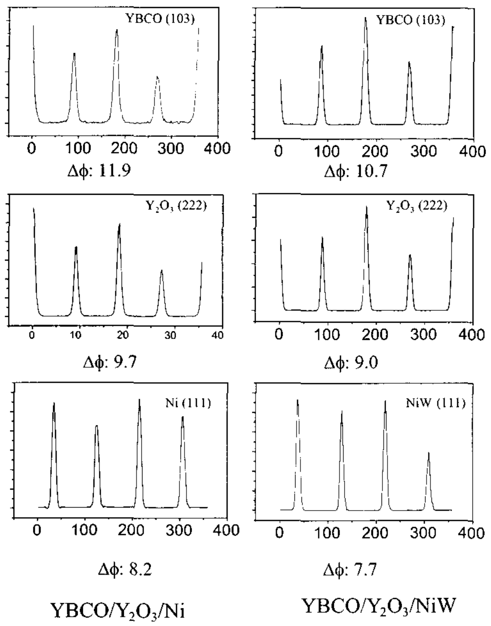


Fig. 4. The I_c and T_c measurements of the best sample of YBCO/Y2O3/NiW with the YBCO thickness of 450 nm and width of 2.8 mm.

oxygen pressure of 500 Torr. The better biaxial texture of NiW was inherited by Y_2O_3 and YBCO film. More important thing is that the reproducibility of good superconducting properties of YBCO on NiW was much better than that on Ni. The T_{c0} of YBCO films on Ni and NiW was about 86~89K. In most cases, the J_c of the sample on NiW is larger than that on Ni, which was consistent wit

the better texture quality of substrate and buffer layers. The best J_c of YBCO/Y_2O_3/Ni with the YBCO thickness of 220 nm was1.0×10^6 A/cm^2 at 77 K and self-field (Fig.3 shows the T_c and I_c plots of the sample). The best J_c of YBCO/Y_2O_3/NiW with the YBCO thickness of 450 nm was1.1×106 A/cm2 at 77 K and self-field (Fig.4 shows the Tc and Ic plots of the sample).

Fig. 5 shows the ϕ-scans of YBCO (103), Y_2O_3 (222), and Ni (111) or NiW (111) reflections, and the in-plane texture of the biaxially metallic substrate is transferred to YBCO through the Y_2O_3 single buffer layer. The FWHM of the ϕ-scans of YBCO/Y_2O_3/Ni are 11.9, 9.7, and 8.2° for the YBCO, Y_2O_3, and Ni, respectively. Meanwhile, the FWHM of the ϕ-scans of YBCO/Y_2O_3/NiW are 10.7, 9.0, and 7.7° for the YBCO, Y_2O_3, and NiW, respectively. Comparison with the ϕ–scan of Ni(111), the Y_2O_3 (222) reflections are rotated 45°. This indicates that the [100] axis of the Y_2O_3 is aligned to the Ni[110] axis in the in-plane direction. The epitaxial relationship can be summarized as Y_2O_3 (001)//Ni(001) and Y_2O_3[100]//Ni[110]



Δϕ: 11.9
Δϕ: 10.7
Δϕ: 9.7
Δϕ: 9.0
Δϕ: 8.2
Δϕ: 7.7

$YBCO/Y_2O_3/Ni$
$YBCO/Y_2O_3/NiW$

Fig. 5. XRD ϕ-scans for the best results of $YBCO/Y_2O_3$ films deposited on biaxially-textured Ni and NiW substrates.

4. CONCLUSIONS

The biaxially textured Y_2O_3 film has been deposited on both Ni and NiW substrates by PLD and was used as a single buffer layer for the YBCO coated conductor. The Y_2O_3 layer was deposited in three steps in order to obtain good biaxial texture and diffusion barrier. The effects of deposition conditions of Y_2O_3 on Ni and NiW were analyzed, which was finally decided by the superconducting properties of YBCO on top of Y_2O_3 buffer layer. For the pure Ni substrate, the better Y_2O_3 film can be deposited in 0.1 mTorr oxygen in second deposition step. However , for NiW substrate, it was better to deposit Y_2O_3 in high vacuum in second step than in 0.1 mTorr oxygen. The J_c of YBCO films on Y_2O_3/Ni and Y_2O_3/NiW are 1.0×10^6 A/cm^2 and 1.1×10^6 A/cm^2 at 77 K and self-field respectively, which indicates Y_2O_3 is a suitable candidate as a single buffer layer for the fabrication of YBCO coated conductor. The reproducibility of good superconducting properties of YBCO on NiW was much better than that on Ni because the biaxial texture of NiW was better than pure Ni, which led to the better biaxial texture of the YBCO films.

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