Preparation and Characterization of Y_2O_3 Buffer Layers and YBCO Films on Textured Ni Tape

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Abstract– **The direct deposition of Y_2O_3 buffer layers on cube-textured nickel tape was successfully performed by electron beam deposition using Y metal which oxidized during deposition. The Y_2O_3 layer exhibited excellent out-of-plane alignment of FWHM of 2.3 ~ 4 ° and good in-plane alignment with ~11 ° FWHM. Surface morphology, crystal orientation and grain size proved to be quite sensitive to the deposition pressure. The surface roughness and the grain size increased with increasing deposition pressure, and the crystal orientation changed from (111)Y_2O_3 to (100)Y_2O_3. Subsequently, YBCO superconducting films were deposited on (100)Y_2O_3 buffer layers by co-evaporation deposition and pulsed-laser deposition (PLD). Though a good in-plane alignment, as measured by X-ray φ-scan , was achieved in the YBCO films, their superconducting characteristics were not so good. The T_c onset was about 84 K for the (00l)YBCO by PLD. The crystal alignment and the microstructure of YBCO superconducting films deposited by the two deposition techniques on cube-textured Ni tapes with Y_2O_3 buffer layers are compared.**

I. INTRODUCTION

The fabrication of YBCO superconducting films on metal tapes is focused on the development of long and flexible conductors because of their potential for high critical current density of ~10^6 A/cm^2 at 77 K. A most important issue is to decrease the density of high angle crystal boundaries. A crystal boundary with misorientation angle greater than ~10 ° behaves like a weak-link and the J_c across such a grain boundary decreases significantly[1], [2]. In order to control the in-plane alignment of polycrystalline YBCO films, several techniques have been developed. Biaxially-aligned yttria-stabilized zirconia (YSZ) buffer layers have been grown on polycrystalline Ni-based alloy tapes by ion-beam-assisted deposition (IBAD) [3], [4]. A process called RABiTS has facilitated the production of the substrate for YBCO films by recrystallization of cold-rolled pure Ni tape by high temperature vacuum annealing.[5] Biaxially-aligned oxide buffer layers, for example, YSZ/CeO_2, can be deposited on the RABiTS Ni tape by several kinds of deposition, such as PLD, sputtering and e-beam deposition. YBCO films deposited on both types of metal tapes have J_c exceeding 10^6 A/cm^2 at 77 K in zero field. Their field dependence is reported to be very similar to films made on $SrTiO_3$ single crystals.

We successfully deposited biaxially-aligned Y_2O_3 buffer layers on cube-textured Ni substrates by electron beam deposition. This technique easily produces the Y_2O_3 buffer layers, needing only control of the deposition pressure. Subsequently, we also deposited YBCO films by co-evaporation deposition and PLD. In this paper, we describe the crystallinity of the Y_2O_3 buffer layers and the YBCO films deposited by these two deposition techniques. The superconducting properties of the YBCO films were briefly investigated.

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II. EXPERIMENT

The Ni metal substrates were prepared by rolling of Ni (99.7%) at room temperature followed by recrystallization annealing at 10^{-6} Torr at temperatures between 600 and 900 °C for several hours. The detailed preparation of the substrates has been reported elsewhere[6]. The Ni substrates were shown to have a cube-texture with {001}<100> orientation. The full-width at half maximum (FWHM) of the out-of-plane and in-plane grain distributions were typically ~6° and ~12°, respectively. These results are shown in Fig. 1.

Y_2O_3 buffer layers were deposited by electron beam deposition using an Y metal evaporation source. The deposition temperature, which was measured on the heater side of the substrate mounting block, was 940 °C. Deposition of Y_2O_3 was conducted in both air (~10^{-5} Torr) and N_2 (5×10^{-4} Torr) atmosphere. In the deposition of Y_2O_3 buffer layers at 5×10^{-4} Torr N_2 atmosphere, first we pumped down to 10^{-5} Torr air, before introducing N_2 gas into the chamber to control the pressure. We have already reported the Y_2O_3 crystal

alignment dependence of the deposition pressure[6]. It is easy to achieve the (100)Y_2O_3 oriented film at a higher deposition pressure; however, the Ni is then easily oxidized. Consequently, N_2 gas was used to deposit at high pressure and low oxygen partial pressure.

YBCO films were deposited by both co-evaporation and PLD. In the case of co-evaporation, the temperature was 850 °C measured at the heater side of holder, similar to the case of a Y_2O_3 deposition. During deposition, pure oxygen gas was introduced near the substrate. After deposition, the films were annealed in 100 Torr of oxygen at T=500 °C. In the case of PLD, the deposition temperature was measured at the surface of the substrate using a pyrometer. The films were deposited at a temperature between 700 and 780 °C at 210 mTorr of O_2 atmosphere and then similarly annealed at ~500 °C for 30 minutes.

The crystal orientation distributions for both YBCO and Y_2O_3 were evaluated by X-ray diffraction, θ-2θ, ω-scan and φ-scan. The surface morphology was observed by scanning electron microscopy (SEM). We measured the J_c at zero field on bridges which were 200 μm wide and 0.5 mm long patterned by photolithography.

III. Results and Discussion

Fig. 1 shows the X-ray rocking curves and φ scans showing the out-of-plane and in-plane alignment for Y_2O_3 buffer layers deposited at ~10^{-5} Torr air and $5x10^{-4}$ Torr N_2, and the Ni

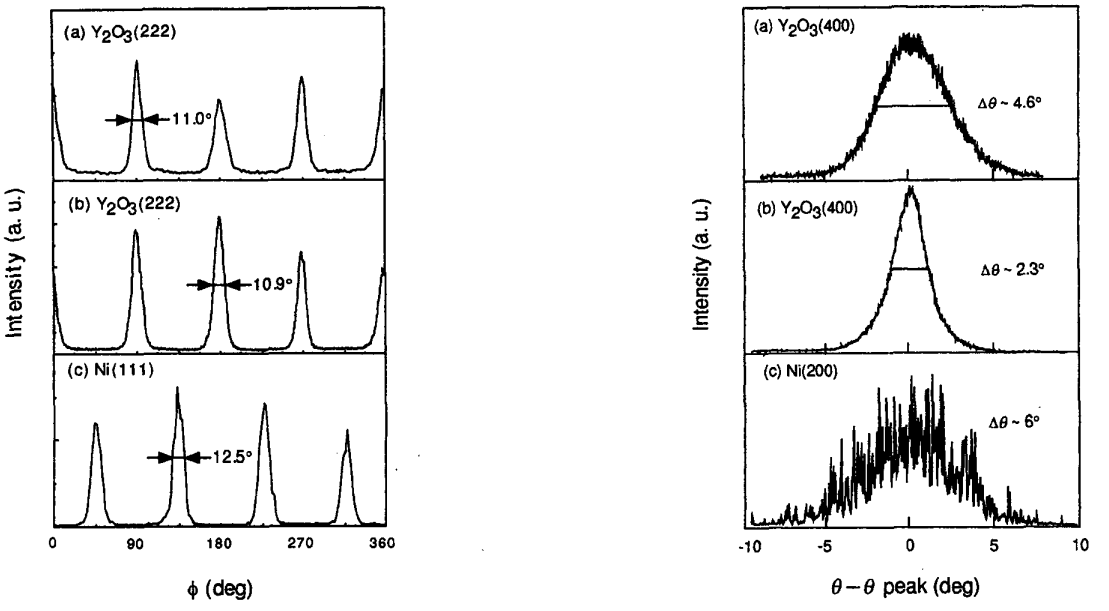

Fig. 1. XRDφ-scans (left) and rocking curves (right) showing the out-of-plane and in-plane FWHM for a Y_2O_3 buffer layer deposited at (a) $5x10^{-4}$ Torr N_2 and (b) ~10^{-5} Torr air. The Ni substrate scans appear in (c).

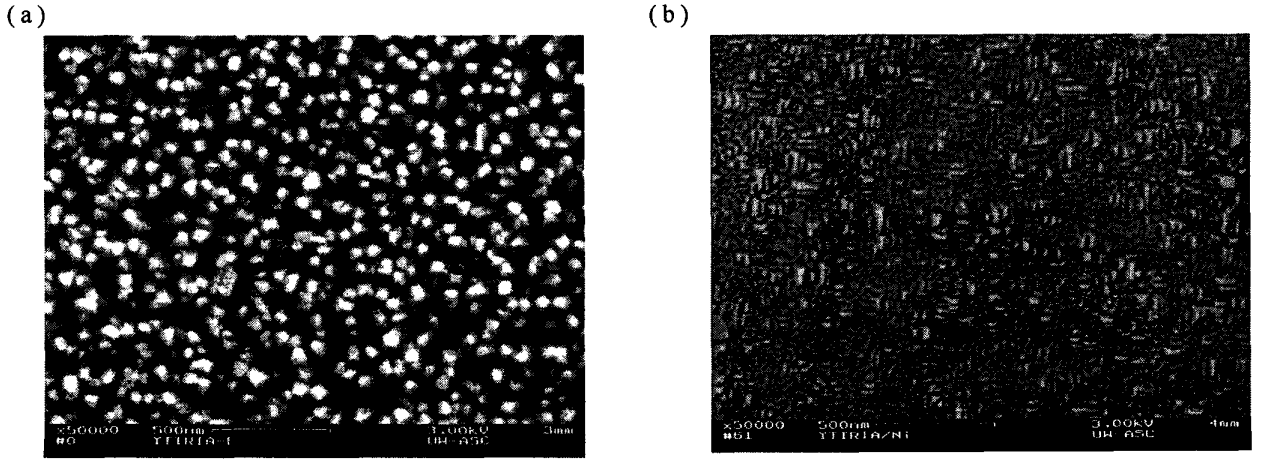

Fig. 2. SEM micrographs for Y_2O_3 films which were deposited at 940°C at (a) $5x10^{-4}$ Torr N_2 and (b) ~10^{-5} Torr air.

substrate. The out-of-plane (FWHM 2.4~4°) for the Y_2O_3 buffer layer is much smaller than the ~6° FWHM for Ni, indicating an improvement in the crystal orientation of the buffer layers. By contrast, the in-plane FWHM for Y_2O_3 and Ni are similar at about 11~12°, indicating good epitaxial growth of Y_2O_3 on Ni. Both Y_2O_3 buffer layers indicate good biaxial alignment. The SEM images of these films deposited at $5x10^{-4}$ Torr N_2 and ~10^{-5} Torr air are shown in Fig. 2(a) and (b), respectively. The grain size and the surface roughness of the buffer layer grown in N_2 are much greater than for Y_2O_3 grown at 10^{-5} Torr. The difference is a result of the different deposition pressure used during growth. The grain size and surface roughness of Y_2O_3 increase with increasing deposition pressure[6].

In YBCO films deposited by co-evaporation, regardless of temperature, the formation of (00l)YBCO was observed on the Y_2O_3 buffer layer deposited at ~10^{-5} Torr air, but (103)YBCO grew on the Y_2O_3 buffer layer deposited under $5x10^{-4}$ Torr N_2. Our (00l)YBCO films have in-plane alignment of 11° FWHM according to the (103)YBCO pole figure shown in Fig. 3(a). This indicates that the (00l)YBCO film grows epitaxially on the Y_2O_3 buffer layer.

In YBCO deposited by PLD, (00l)YBCO was observed to form on the Y_2O_3 buffer layer deposited at ~10^{-5} Torr air. An in-plane alignment of 10° FWHM was obtained. The (103)YBCO pole figure is shown in Fig. 3(b). In the case of the Y_2O_3 buffer layer deposited at $5x10^{-4}$ Torr N_2, YBCO films deposited at 730 °C and 760 °C have predominantly an a-axis and a (103) orientation, respectively.

We also observed the surface morphology of both (100) and (00l) YBCO films by SEM. These results are shown in Fig. 4(a), (b), respectively. The surface morphology of both films is very smooth. The grain shape for the (100)YBCO film is rather rectangular with strong grain alignment. The shorter length of the rectangular grains is about 0.1 μm, slightly larger than the Y_2O_3 grain size shown in Fig. 2(a). The (103) oriented grains also have a similar size. On (00l)YBCO film, growth islands with well-defined terraces were observed by high

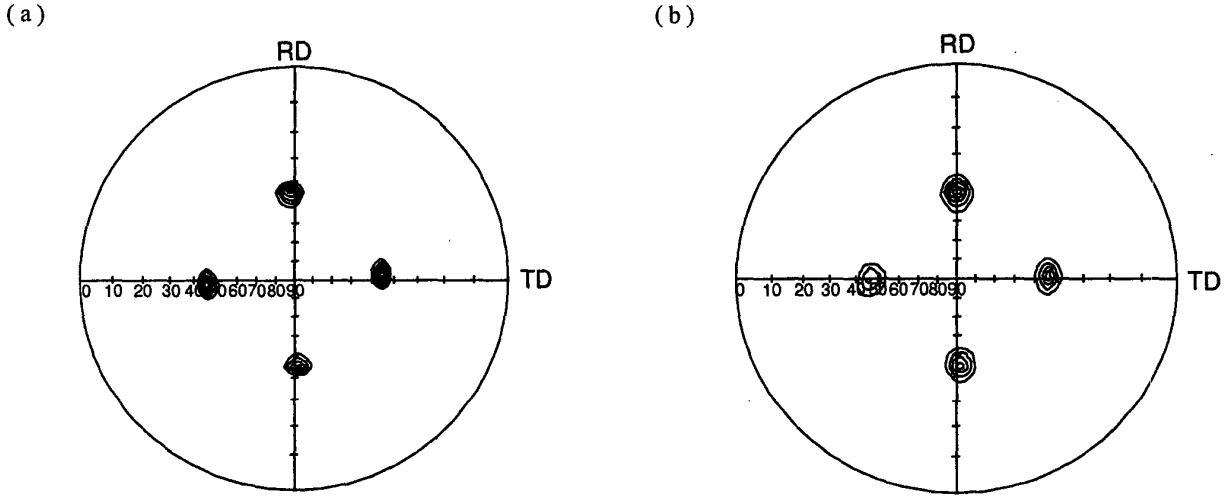

Fig. 3. (103)YBCO pole figures of films deposited by (a) co-evaporation and (b) PLD.

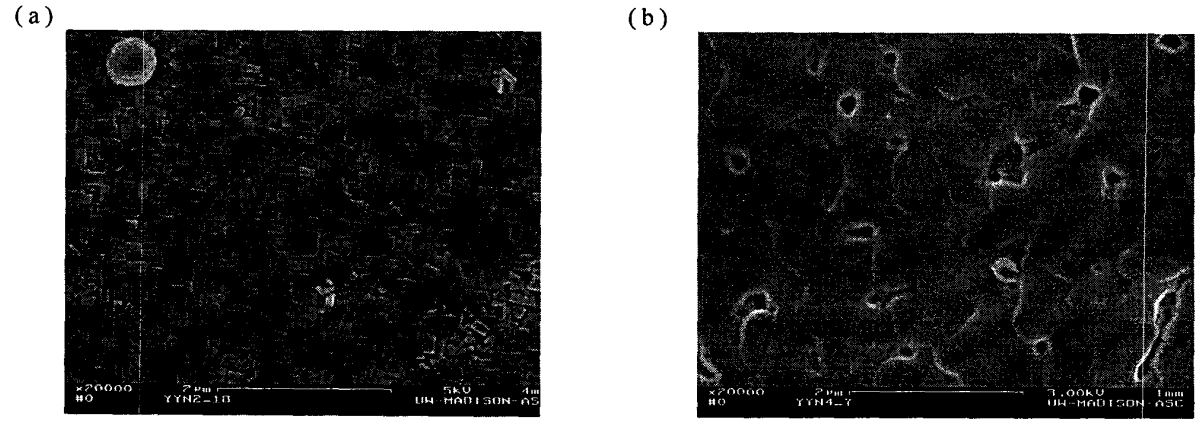

Fig. 4. SEM micrographs of PLD YBCO films on Y_2O_3 buffer layers deposited at pressures of (a) $5x10^{-4}$ Torr N_2 and (b) ~10^{-5} Torr air.

resolution SEM as shown in Fig. 4(b). The size of the islands ranged from 300 to 600 nm in mean diameter. The grain-to-grain connectivity does appear to be good.

We measured the temperature dependence of the electrical resistance of PLD (00l)YBCO films between room temperature and 77 K. The T_c onset was about 84 K, indicating that the deposition conditions of the YBCO films have not yet been optimized. The J_c of this sample was $<10^5$ A/cm^2 at 77 K, probably because of the low T_c.

IV. Summary

We prepared Y_2O_3 buffer layers on cube-textured Ni under two different deposition pressures, $\sim 10^{-5}$ Torr air and 5×10^{-4} Torr N_2. Though both buffers possessed good biaxial alignment, their surface morphologies were very different. The Y_2O_3 buffer layer deposited at a higher deposition pressure had a larger grain size and a rougher surface than that deposited at a lower deposition pressure. The out-of-plane FWHM for both of the Y_2O_3 buffer layers became narrower than the one for Ni, indicating an improvement in out-of-plane alignment. The in-plane FWHM for the buffer layer is almost the same as that of the underlying Ni. While the YBCO films deposited by co-evaporation and PLD on Y_2O_3 buffer layers, which were deposited at a lower deposition pressure, have a c-axis orientation, the YBCO films deposited by co-evaporation and PLD on Y_2O_3 buffer layer deposited under a higher pressure have a (103) or an a-axis orientation. The grain size of the a-axis or (103) oriented film by PLD is similar to the Y_2O_3 grain size. The crystal orientation and grain size were affected significantly by the surface roughness. The grains in the (00l)YBCO films made by PLD were well connected with low porosity. The good crystallinity and morphology lead us to expect high J_c values, once the YBCO growth conditions are optimized. However, we believe these results provide evidence that e-beam deposited Y_2O_3 buffer layers can be optimized for the fabrication of a YBCO superconducting tape. We expect that the Y_2O_3 buffer layer has significant value for coated conductors because of its easy fabrication, small lattice mismatch to YBCO, and high chemical stability.

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