Fabrication of High J_c $YBa_2Cu_3O_{7-\delta}$ Tapes Using the Newly Developed Lanthanum Manganate Single Buffer Layers

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***Abstract*—High J_c $YBa_2Cu_3O_{7-\delta}$ (YBCO) films have been fabricated on $LaMnO_3$ buffered ion-beam assisted deposition (IBAD) MgO template layers. A $LaMnO_3$ buffer layer is compatible with MgO surfaces and also provides a good template for growing high current density YBCO films. $LaMnO_3$ buffer layers were deposited using rf magnetron sputtering. On $LaMnO_3$-buffered-MgO (100) single crystal substrates, YBCO films with a J_c of over 4 M/cm^2 were grown using both pulsed laser deposition (PLD) and ex-situ BaF_2 process. Using PLD, J_c of 1.8 MA/cm^2 at 77 K was obtained on 200-nm-thick YBCO films grown on $LaMnO_3$-buffered MgO IBAD/Ni-alloy substrates. In addition, an I_c of 230 A/cm-width was obtained for 1.65-μm-thick YBCO films grown on $LaMnO_3$-buffered MgO IBAD/Ni-alloy substrates using PLD at Los Alamos National Laboratory. This performance is comparable to the best single-layer results achieved on IBAD-MgO substrates.**

***Index Terms*—Buffer layers, coated conductors, IBAD-MgO substrates, YBCO.**

I. Introduction

ROLLING-ASSISTED Biaxially Textured Substrates (RABiTS) [1]–[3] and Ion-Beam Assisted Deposition (IBAD) [4], [5] approaches have emerged as leading techniques for the fabrication of second generation $YBa_2Cu_3O_{7-\delta}$ (YBCO) coated conductors. In the RABiTS approach, standard architecture of CeO_2 /YSZ/ Y_2O_3/Ni/Ni-W is utilized to produce meter lengths of buffered tapes. Here, the Y_2O_3 seed layer is typically grown by reactive evaporation [6]. Both YSZ barrier and CeO_2 cap layers are grown by rf magnetron sputtering. In an effort to develop alternative single buffer layer technology for YBCO coated conductors, we have recently demonstrated the growth of YBCO films with a J_c of over 1.2 MA/cm^2 at 77 K and self-field on $LaMnO_3$ (LMO)-buffered Ni-W substrates [7], [8]. $LaMnO_3$ was identified as a good diffusion barrier for Ni. $LaMnO_3$ is an orthorhombic perovskite with lattice parameters, $a = 5.533$ Å, $b = 5.722$ Å, $c = 7.694$ Å, respectively. The pseudocubic lattice parameter of 3.88 Å is closely matched to YBCO: the lattice mismatch is less than 0.8%. Following the successful demonstration of the growth of YBCO films on $LaMnO_3$ buffered Ni-W substrates, single buffer layer technology was also extended to IBAD substrates. In this paper, we report our first demonstration of the growth of high current density YBCO films on $LaMnO_3$-buffered IBAD MgO template layers.

Manuscript August 6, 2001. This work was supported by the U.S. Department of Energy, Division of Materials Sciences, Office of Science, Office of Energy Efficiency and Renewable Energy. The work was performed at the Oak Ridge National Laboratory, managed by U.T.-Battelle, LLC for the U.S. Department of Energy under Contract DE-AC05-00OR 22725.

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Digital Object Identifier 10.1109/TASC.2003.811826

II. Experiment

Highly textured IBAD MgO templates on metallic substrates were received from Los Alamos National Laboratory (LANL). The details of the substrate fabrication will be published elsewhere [9]. In order to determine the compatibility of $LaMnO_3$ with MgO surfaces, $LaMnO_3$ buffers were also deposited on 1 cm $\times$ 1 cm MgO (100) single crystal substrates. RF-magnetron sputtering was used to deposit $LaMnO_3$ layers using the oxide targets. The sputter targets were made from the single phase LMO powders, prepared by solid-state reaction, which were loosely packed into a 4" copper tray. Typical sputter conditions consisted of 2-5 $\times 10^{-5}$ Torr of H_2O with a total pressure of 3 mTorr forming gas (Ar/ H_2 4%). The LMO films were grown at a substrate temperature of 650-750 °C. The water pressure is sufficient to oxidize the film to form stoichiometric $LaMnO_3$. The forming gas was used to reduce any oxide present at the substrate surface during the film growth. The LMO film thickness was varied from 60 to 300 nm. The deposition rate was $\sim$ 0.06 nm/sec.

YBCO films were grown by both pulsed laser deposition (PLD) and an ex-situ BaF_2 process [10], [11]. The PLD system at ORNL uses a XeCl excimer laser system operated at an energy density of $\approx$ 2 J/cm^2 and a repetition rate of 10–20 Hz. During YBCO deposition, substrates were maintained at 780 °C and 120 mTorr of O_2. Typical YBCO film thickness was 200 nm. The details of the LANL PLD system were reported elsewhere [12]. The films were analyzed by a Philips Model XRG3100 X-ray diffractometer (XRD) and microstructural analyzes were conducted on a JOEL Model JSM-840 scanning electron microscope (SEM). The thickness and composition of both LMO and YBCO films were determined by Rutherford backscattering spectroscopy (RBS). Atomic Force Microscopy (AFM) was used to study the surface roughness of the samples. The resistivity and transport critical current density, J_c, were measured using a standard four-probe

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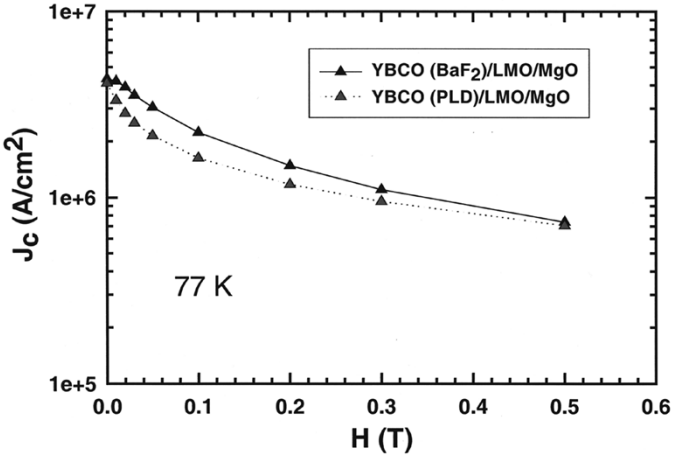

Fig. 1. Field-dependence of the transport current density, J_c for both 200 nm thick PLD YBCO (solid line) and 300 nm thick BaF_2 YBCO (dashed line) films on $LaMnO_3$-buffered MgO (100) single crystal substrates.

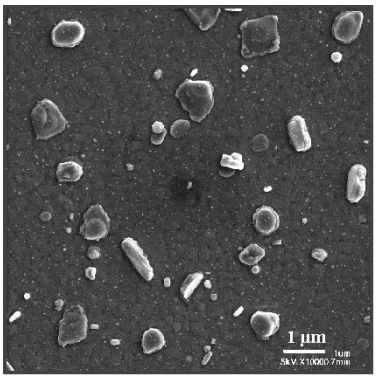

Fig. 2. SEM micrograph for a 200 nm thick PLD YBCO film on $LaMnO_3$-buffered MgO (100) single crystal substrate.

technique. The voltage contact spacing was 0.4 cm. Values of J_c were calculated using a 1 μV/cm criterion.

III. Results and Discussion

A. YBCO Films on $LaMnO_3$-Buffered MgO (100) Single Crystal Substrates

Detailed X-ray diffraction studies indicated the presence of highly textured YBCO and $LaMnO_3$ films on MgO single crystal substrates. The field dependence of J_c for YBCO films grown using both PLD and ex-situ BaF_2 process on $LaMnO_3$-buffered MgO substrates is shown in Fig. 1. A zero-field J_c of 4.3 MA/cm^2 at 77 K was obtained. YBCO BaF_2 films carried an I_c of 143 A/cm-width. J_c at 0.5 T was about 20% of the zero-field J_c. This indicates the presence of a strongly linked YBCO film. The SEM microstructure of a PLD YBCO film on $LaMnO_3$-buffered MgO substrate (Fig. 2) is consistent with the appearance of a high quality film. There is good uniformity in porosity and surface particulate over the film surface. These results indicate that $LaMnO_3$ is potentially compatible with both MgO and YBCO using either PLD or the BaF_2 process.

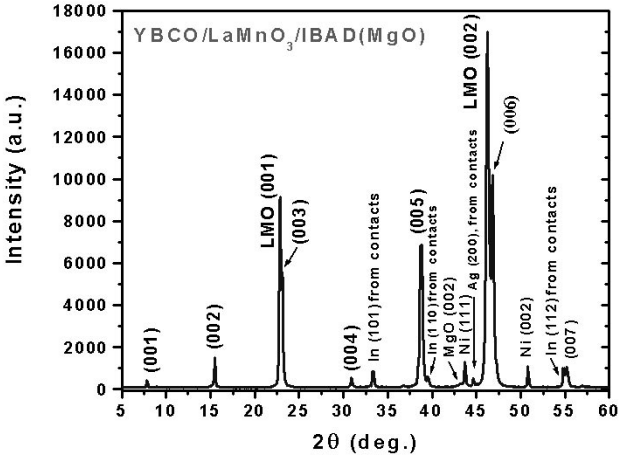

Fig. 3. Typical θ –2θ scan for a 200 nm thick YBCO film on 300 nm thick $LaMnO_3$-buffered IBAD MgO/Ni-alloy substrate.

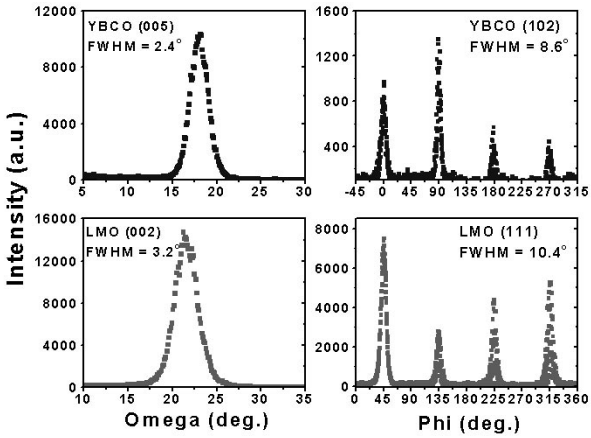

Fig. 4. ω and ϕ scans for a 200 nm thick YBCO film on 300 nm thick $LaMnO_3$-buffered IBAD MgO/Ni-alloy substrate.

B. YBCO Films on $LaMnO_3$-Buffered IBAD MgO Templates on Metallic Substrates

A typical θ –2θ scan for a 200 nm thick YBCO film grown by PLD on LMO-buffered IBAD MgO/Ni-alloy substrate is shown in Fig. 3. Remarkably, despite the good compatibility on single crystal MgO substrates, high-quality YBCO coatings thus far have not been produced using the BaF_2 ex situ process on LMO buffered metallic substrates. The reason for this discrepancy is currently not understood and remains under investigation. The PLD-grown film, on the other hand, shows strong YBCO (00l) signals, indicating good c-axis growth. Presence of NiO impurities was also not observed. Results from ω and ϕ scans (Fig. 4) revealed good epitaxial texturing. The full width at half maximum (FWHM) values for LMO (002), and YBCO (005) are 3.2°, and 2.4°, and those of LMO (111), and YBCO (102) are 10.4°, and 8.6°, respectively. MgO diffraction patterns were weak due to the presence of very thin MgO layers.

The field dependence of J_c for the PLD-grown YBCO on $LaMnO_3$-buffered IBAD MgO templates is shown in Fig. 5. A zero-field J_c of 1.8 MA/cm^2 at 77 K was obtained. The YBCO

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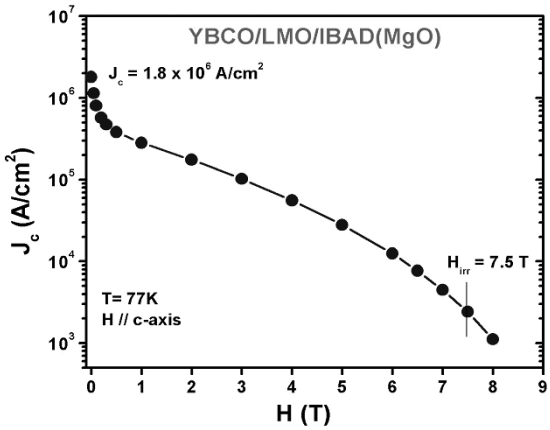

Fig. 5. Field-dependence of the transport current density, J_c for a 200 nm thick YBCO film on 300 nm thick $LaMnO_3$-buffered IBAD MgO/Ni-alloy substrate.

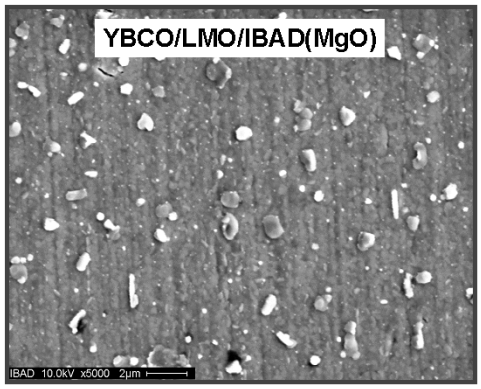

Fig. 6. SEM micrograph for a 200 nm thick PLD YBCO film on 300 nm thick $LaMnO_3$-buffered IBAD MgO/Ni-alloy substrate.

films had good flux pinning properties. An irreversibility field of 7.5 T was also observed. SEM microstructure of this YBCO film surface is shown in Fig. 6. Similar to the YBCO on single crystal MgO, this indicates a dense film morphology. In addition, a YBCO film with a thickness of 1.65 μm was grown at LANL on $LaMnO_3$ buffered IBAD MgO templates. This film carried an I_c of 230 A/cm at 75 K. These results demonstrate that $LaMnO_3$ is compatible with IBAD MgO templates.

IV. Summary

In summary, we have demonstrated the successful fabrication of high performance YBCO coatings on a *single* buffer layer of $LaMnO_3$ deposited on both MgO single crystal substrates and IBAD MgO templates on metallic substrates. An I_c of 230 A/cm-width was obtained on YBCO films grown on $LaMnO_3$ buffered IBAD MgO templates. This performance is comparable to the best single layer results achieved on IBAD MgO substrates including the newly developed $SrRuO_3$ layer at Los Alamos National Laboratory.

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