

ION-BEAM-ASSISTED DEPOSITION OF MAGNESIUM OXIDE FILMS FOR COATED CONDUCTORS

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ABSTRACT

The development of high critical-temperature thin-film superconductors and coated conducting wires is important for electric power applications. To achieve high transport current density, template films are necessary for the successful deposition of biaxially aligned $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) on flexible metal substrates. We grew biaxially aligned magnesium oxide (MgO) template films by ion-beam-assisted deposition with electron-beam evaporation. MgO films of ≈ 100 Å thickness were deposited on Si_3N_4 -coated Si substrates at a deposition rate of ≈ 1.5 Å/sec with an ion flux of $\approx 110 \mu\text{A}/\text{cm}^2$ bombarding the substrate at a 45° angle. To study crystalline structure by X-ray diffraction, we deposited an additional layer of MgO. Good in- and out-of-plane alignment was observed, with (111) ϕ -scan full-width half-maximum (FWHM) of 6.2° and (002) ω -scan FWHM of 2.2° .

INTRODUCTION

High-temperature superconducting wires and tapes have a variety of applications, including transmission wires and microwave devices [1,2]. Fabrication of tapes that can carry the necessary current has been the focus of a great deal of research. Production of high temperature superconducting

YBa₂Cu₃O_{7-x} (YBCO) tapes on nonaligned metallic substrates requires high-quality biaxially textured template layers. Yttria-stabilized zirconia (YSZ) has been used successfully as a template layer when deposited by the ion-beam-assisted deposition (IBAD) process. While superconducting films made with YSZ buffer layers have been successful, with transport current densities $\approx 10^6 \text{ A/cm}^2$, a limitation to the production process is the time required for YSZ deposition. Due to the competitive growth process of YSZ, films with thickness of $\approx 8,000$ to $10,000 \text{ \AA}$ are necessary in order to achieve the desired in-plane alignment of $\approx 13^\circ$ [3,4]. The excessive time required to deposit such films has driven the search for new buffer-layer materials.

MgO, on the other hand, exhibits a much more rapid growth mechanism. Because texturing of MgO begins at the nucleation stage, its films need only be $\approx 100 \text{ \AA}$ thick in order to obtain quality texture [5-7]. Processing times for these films are thus reduced by at least one order of magnitude from those of YSZ films [8]. Using MgO buffer layers is a significant step toward producing high critical-temperature superconductors for practical applications.

We grew biaxially textured MgO films on Si₃N₄ substrates with the IBAD process and an e-beam evaporation system. An additional homoepitaxial layer was deposited in order to facilitate film characterization via X-ray analysis; ϕ -scans and ω -scans were used to analyze film texture.

EXPERIMENTAL PROCEDURE

IBAD MgO films were deposited on as-received Si₃N₄ substrates measuring $\approx 1 \times 0.5 \text{ cm}$ and mounted on a heatable stage with silver paste. A 3 cm Kaufman-type ion source was used to accelerate argon ions at 750 eV. All substrates were presputtered for 5 minutes before deposition. The angle of incidence, α , for the ion beam was maintained at 45° , the channeling direction for

MgO. A Faraday cup was used to measure the beam current density of $110 \mu\text{A}/\text{cm}^2$. A 10:1 argon-to-oxygen ratio provided a background pressure of 8×10^{-5} torr during IBAD. Vapor flux was provided by e-beam evaporation and monitored with a quartz crystal monitor at $1.5 \text{ \AA}/\text{s}$ for an ion-to-atom ratio of ≈ 0.9 . The IBAD films were deposited to a thickness of 100 \AA . The experimental setup is illustrated in Fig. 1 and deposition conditions are given in Table 1.

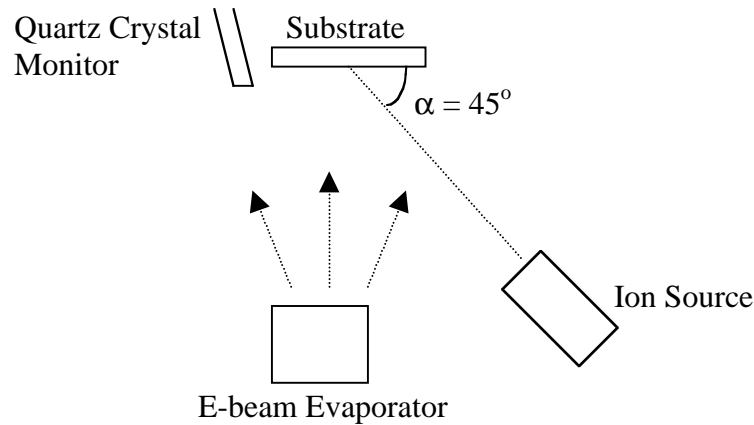


Fig. 1. Experimental setup for IBAD process.

After IBAD MgO deposition, the substrates were heated to $\approx 300^\circ\text{C}$ before addition of a homoepitaxial layer of MgO deposited without ion fluence. The homoepitaxial layer was necessary in order to characterize the films by x-ray diffraction and is $\approx 1000 \text{ \AA}$ thick. Oxygen flow was introduced into the system at a rate of $\approx 0.35 \text{ sccm}$ during deposition. The deposition rate for the homoepitaxial layer was the same as that for IBAD ($1.5 \text{ \AA}/\text{s}$).

Table 1. Deposition conditions for biaxially textured IBAD MgO films.

Operating Pressure	8×10^{-5} torr
Deposition Rate	1.5 Å/s
Ion beam incident angle	45°
Beam energy	750 eV
Ion fluence	110 $\mu\text{A}/\text{cm}^2$
Gas flow (Ar + O ₂)	3.35 sccm

RESULTS AND DISCUSSION

Biaxial texture of the IBAD MgO films was characterized by X-ray ϕ -scans and ω -scans. In-plane texture determined by the full-width half-maximum (FWHM) of (111) ϕ -scans is illustrated in Fig. 2. The average FWHM is 6.2°, which compares favorably with the obtainable in-plane texture of YSZ films.

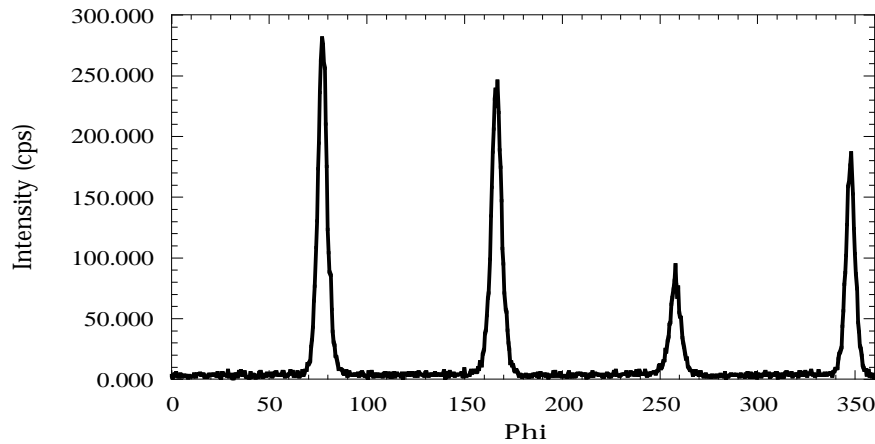


Fig. 2. X-ray diffraction phi-scan of MgO film.

Out-of-plane texture as characterized by the ω -scan of Fig. 3, shows a FWHM of 2.2°. The appearance of high-quality texture in films of only ≈ 100 Å thickness illustrates the nucleation growth mechanism of IBAD MgO films. Our experience has shown that texture deteriorates rapidly if film thickness deviates more than

≈ 20 Å from this thickness. The relationship between film texture and thickness of the film was analyzed and described in reference 9; our experiments support these findings. Figure 4 shows diffraction patterns from a series of 2-theta scans performed on films of varying thickness. All films were deposited on Si_3N_4 substrates under the growth conditions mentioned previously. The figure

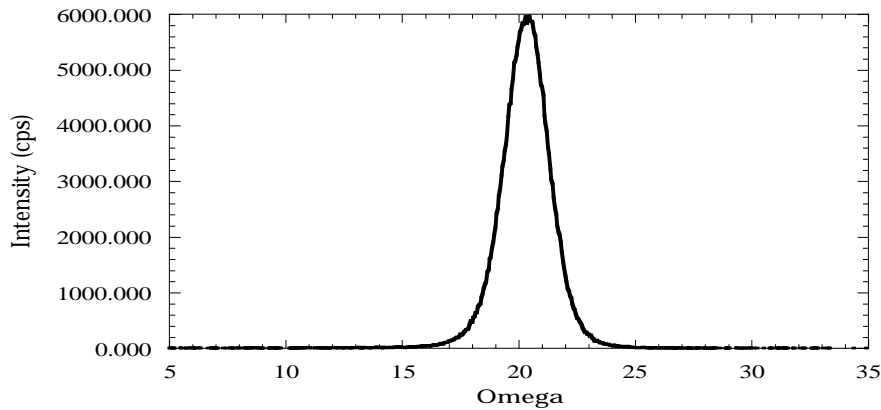


Fig. 3. X-ray diffraction omega-scan of MgO film.

illustrates the presence of the MgO $\langle 200 \rangle$ peak at ≈ 75 Å, followed by a much stronger peak in films of ≈ 100 Å thickness. In films of ≈ 125 Å, the $\langle 200 \rangle$ peak becomes much less intense and the presence of the $\langle 220 \rangle$ peak is evident.

Phi-scans of our films of various thickness also exhibit the broadening of FWHM values to $\approx 8^\circ$ for films of ≈ 80 Å and $\approx 15^\circ$ for films of ≈ 120 Å. The results of our studies of these films agree with the critical thickness for optimal texture of IBAD MgO films at 100 Å thickness.

We also performed studies on deposition temperature for the homoepitaxial layer. Immediately after deposition of the IBAD layer, the films were heated to 300, 400, and 500°C for the subsequent application of the 1000 Å homoepitaxial layer. Our preliminary findings indicate no observable difference

in obtainable texture among these deposition temperatures and hence no apparent advantage to depositing at the higher temperatures of 400 and 500°C.

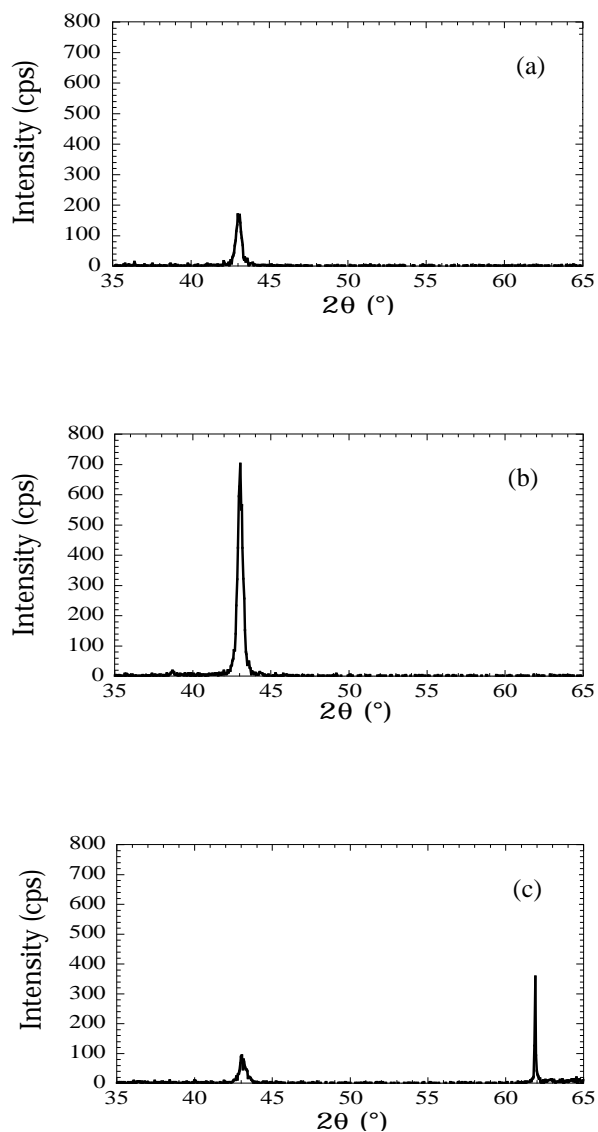


Fig. 4. X-ray 2-theta scans for IBAF MgO films of (a) 75 Å, (b) 100 Å, and (c) 125 Å thickness.

CONCLUSIONS

Biaxially textured MgO films were successfully grown by using the IBAD MgO process. MgO films grown with this approach require much less time than IBAD YSZ films and exhibit favorable texture. We examined texture variation with respect to film thickness and found the in- and out-of-plane texture to be optimal in films of ≈ 100 Å thickness. Additionally, our research indicates that these films can be fabricated at a homoepitaxial deposition temperature of only 300°C. IBAD MgO films having in-plane texture of 6.2° and out-of-plane texture of 2.2° were observed. This work has demonstrated that high quality textured MgO films can be grown with the IBAD process in very thin films (≈ 100 Å) in a very time-efficient manner. Such films are excellent candidates for buffer layers in the fabrication of YBCO coated conductors.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, as part of a DOE program to develop electric power technology, under Contract W-31-109-Eng-38.

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