Growth and characterization of Sm-Ba-Cu-O films and other RE-Ba-Cu-O films on PLD-CeO₂ / IBAD-GZO / metal substrates

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Abstract. We have formed SmBa₂Cu₃O₇₋ₓ (Sm-123) films on PLD-CeO₂ / IBAD-GZO / metal substrates which are suitable for coated conductors. Characteristics of the SmBa₂Cu₃O₇₋ₓ films were affected by O₂ gas pressure during deposition through film crystallinity. For the film 0.25 μm in thickness deposited under 500 mTorr O₂ gas pressure, we obtained a Jc of 2.2MA/cm² and Tc of 92.5 K. We also measured the dependence of Jc on applied magnetic field angle for Sm-123 films and compared to REBa₂Cu₃O₇₋ₓ (RE = Y, Er, Gd) films. The Jc of the Sm-123 films had peaks at the angle where the magnetic field was parallel and perpendicular to c-axis. Under the magnetic field parallel to the c-axis of the films, the REBa₂Cu₃O₇₋ₓ (RE = Y, Er, Gd) films which had high Jc of 2 to 3 MA/cm² in self-field showed similar Jc values. On the contrary, under the magnetic field parallel to the c-axis, the Jc exhibited large difference depending on the RE elements.

1. Introduction
Recently coated conductor using YBa₂Cu₃O₇₋ₓ (Y-123) films has been intensively studied and the Jc has been improved. For applications of coated conductors to equipment, enhancement of Jc in magnetic field is needed as well as high Ic under self-field. High-Tc superconductors have high Jc under magnetic field perpendicular to c-axis essentially because of intrinsic pinning. So efforts have been made to improve the Jc under magnetic field parallel to the c-axis [1], [2], [4], [5]. One of the efforts is investigation of substitution of yttrium in Y-123 by other rare earth elements [2], especially light rare earth elements such as Sm [3] and Gd. These materials have high Tc and improved characteristics in magnetic field. Yoshida et al reported high Jc under magnetic field for Sm₁₊ₓBa₂₋ₓCu₃O₇₋ₓ films grown under low temperature using c-axis oriented seed layer on MgO substrates [4]. We also reported good magnetic field dependence of Jc for GdBa₂Cu₃O₇₋ₓ (Gd-123) films fabricated on metal substrates using PLD-CeO₂ / IBAD-GZO buffer layer [5]. In this study we have found suitable deposition condition to obtain high Jc SmBa₂Cu₃O₇₋ₓ (Sm-123) films on PLD-CeO₂ / IBAD-GZO / metal substrates and examine their Jc dependence on applied magnetic field angle.
2. Experimental
The Sm-123 films were grown by PLD on the PLD-CeO₂ / IBAD-GZO / metal substrates [6], [7]. The \( \phi \)-scan FWHM of buffer layer CeO₂ was around 4.6 degrees. The size of the substrates was 10 x 10 mm, and deposition area of superconductor films was 9 x 9 mm. We used KrF excimer laser for PLD and composition of a target was \( \text{Sm}_1\text{Ba}_2\text{Cu}_3\text{O}_7-x \). The crystal axis orientation and c-axis length of the films were confirmed by XRD 0-2θ measurements. After XRD 0-2θ measurements, a silver protecting layer was deposited on the superconductor layer and annealed in \( \text{O}_2 \) gas flow. The measurements of \( T_c \) and \( J_c \) in liquid nitrogen were performed using the 4-probe method. The deposition conditions and characteristics are summarized in table 1.

We measured magnetic field angle (\( \theta \)) dependence of \( J_c \) under 0.3 T, 1 T, 3 T and 5 T of magnetic field (B) using the 4-probe method in liquid nitrogen. The distance between the voltage taps was 2 mm and a 5 \( \mu \)V/cm of \( I_c \) criterion was applied. The direction of the transport current is perpendicular to the magnetic field. The \( \text{ErBa}_2\text{Cu}_3\text{O}_7-x \) (Er-123) films were fabricated in the same way. The detail of the characteristics of Y-123 films and Gd-123 films are described in reference [5].

| Sample   | PLD gas pressure (mTorr) | Length of c-axis | Thickness (µm) | \( J_c \) (0T, 77K) (MA/cm²) | \( T_c \) (K) |
|----------|--------------------------|------------------|----------------|--------------------------------|--------------|
| S25-300  | 300                      | 11.759           | 0.25           | 1.08                           | 91.8         |
| S25-400  | 400                      | 11.770           | 0.25           | 1.67                           |             |
| S25-500  | 500                      | 11.770           | 0.25           | 2.47                           | 92.5         |
| S83-500  | 500                      | 11.759           | 0.83           | 1.29                           |             |

3. Results and discussion
The characteristics of Sm-123 films were affected by \( \text{O}_2 \) gas pressure during the PLD process. Figure 1 shows gas pressure dependence of \( J_c \) and XRD (005) peak intensity for the Sm-123 films with thicknesses of 0.25 µm. The \( J_c \) increased with increasing gas pressure from 300 mTorr to 500 mTorr and reached 2.2 MA/cm² at 500 mTorr. The XRD peak intensity also increased according to the gas pressure, and then crystallinity was considered to be improved.

Figure 2 shows \( J_c \) dependence on magnetic field angle (\( J_c \)-B-\( \theta \)) for 0.3 T and 3T, and dependence on magnetic field intensity (\( J_c \)-B). The data of the Sm-123 film of 0.83 µm thickness deposited under 500 mTorr gas pressure is also shown in the figure 2. The film deposited under 300 mTorr gas pressure (S25-300) showed a larger \( J_c \) drop even in a small magnetic field perpendicular to the c-axis. The intrinsic pinning of the sample S25-300 is not strong because of poor crystallinity that weakens the XRD peak intensity.

As to the effect of the film thickness, the 0.25 µm-thick film (S25-500) and 0.83 µm-thick film
(S83-500) showed almost the same magnetic field angle and intensity dependence in spite of large deference of Jc in 0 T. This indicates a homogeneous distribution of c-axis oriented pinning centers and the homogeneous crystallinity in the films deposited a 500 mTorr O2 pressure. On the other hand, the grain boundary, which affect the Jc in 0 T, may not be homogeneous along film thickness because of the effect of the CeO2 layer. Therefore, the Sm-123 films are expected to show high Ic in thick films under magnetic field.

In figure 3, the Jc-B characteristics of the Sm-123 film deposited under 500 mTorr gas pressure is shown with those of Er-123, Gd-123 and Y-123 films. Thickness of these films is 0.25 μm. Under the magnetic field perpendicular to the c-axis over 1 T, all of the films have similar Jc values. By the deposition process using 500 mTorr gas pressure, we obtained Sm-123 films with good crystallinity and a high Jc of 2.2 MA/cm². Therefore, for the Sm-123 film, which was improved by 500 mTorr deposition and has good crystallinity, the intrinsic pinning caused by the layered structure is almost same level as the other RE-123 films.

On the contrary, the Jc under magnetic field parallel to the c-axis varied according to the RE elements (figure 3a). Sm-123 film has larger Jc in the magnetic field parallel to the c-axis than Er-123 and Y-123 films. However the Jc of the Sm-123 film is a little smaller than that of the Gd-123 film. On the other hand, Yoshida et al showed high Jc of the Sm-123 films grown under low temperature in B // c-axis [4]. In our case, higher deposition temperature of the Sm-123 film (790-805 °C) compared to Gd-123 (730 °C [5]) film may cause difference of crystallinity, and therefore Jc characteristics in the magnetic field.

4. Summary
We fabricated Sm-123 superconductor films on the PLD-CeO2 / IBAD-GZO / metal substrates by PLD. The characteristics of the Sm-123 were affected by O2 gas pressure during PLD process. We
obtained $J_c$ of 2.2 MA/cm$^2$ (77 K, self-field) for Sm-123 film of 0.25 μm thickness. The Sm-123 film had similar $J_c$-B characteristics to the Gd-123 film which shows a peak at the angle of $\theta$ = 0 deg. These $J_c$-B characteristics are kept up to a thickness of 0.83 μm showing homogeneous distribution of the pinning centers and crystallinity, and therefore the Sm-123 films are expected to have high $I_c$ in thick films under magnetic field.

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Figure 3. $J_c$ dependence on magnetic field ($J_c$-B) of RE-123 films for B parallel to the c-axis (a) and perpendicular to the c-axis. (b) normalized $J_c$ versus B for B parallel to the c-axis. $J_c$ values in 0 T are indicated in parenthesis. (c) at 77 K. RE elements are Sm (circle), Er (square), Gd (triangle) and Y (diamond). Thickness of all the films is 0.25 μm.

(a) (b) (c)