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High critical current density and its magnetic fields dependence in (Sm,Eu,Gd)$Ba_2Cu_3O_y$ films by using multiple targets

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ABSTRACT

Melt textured bulks of $(Sm_{0.33}Eu_{0.33}Gd_{0.33})Ba_2Cu_3O_y$ (SEG123) show high J_c compared with that of $YBa_2Cu_3O_y$ (Y123), because of nanoscopic network consisting of crossing rare earth (RE) compositional stripes. In this study, we fabricated SEG123 films by using pulsed laser deposition (PLD) method on $LaAlO_3$ (LAO) substrates and evaluated the J_c and T_c in magnetic field. J_c of the SEG123 film was typically 1.4 MA/cm^2 at 77 K in self-field. J_c in self-field of SEG123, Y123 and Sm123 films were almost the same value, however, J_c in magnetic fields showed a notable difference. The J_c of SEG123 film were 62.7 kA/cm^2 at 5 T. We conclude that the J_c in magnetic fields were improved by RE-rich particle made of RE/Ba substitution acting as 3-dimensional pinning centers. Moreover we have confirmed that the superconducting properties changes by varying Sm, Eu and Gd composition ratio.

1. Introduction

Recently many groups have investigated $REBa_2Cu_3O_y$ (RE123, RE = rare earth) films because RE123 have an important potential for high magnetic field applications. In order to improve the critical current density (J_c) in magnetic fields, it is effective to introduce artificial pinning centers (APCs) into RE123 films. In early reports, many APC materials have been reported such as $BaSnO_3$ [1], $BaZrO_3$ [2] and Y_2O_3 [3]. We have reported $Sm_{1.04}Ba_{1.96}Cu_3O_y$ (SmBCO) films prepared by low-temperature growth (LTG) technique [4]. The LTG-SmBCO films showed high-J_c in magnetic field compared with conventional SmBCO films prepared by pulsed laser deposition (PLD) method. We argued that high-density and nanosized low-T_c particles, which consisted of Sm-rich particles caused by Sm/Ba substitutions, were included within the LTG-SmBCO films and these low-T_c particles act as 3-dimensional APC.

Melt textured bulks of $(Nd_{0.33}Eu_{0.33}Gd_{0.33})Ba_2Cu_3O_y$ (NEG123) [5] and $(Sm_{0.33}Eu_{0.33}Gd_{0.33})Ba_2Cu_3O_y$ (SEG123) [6] show high J_c compared with that of $YBa_2Cu_3O_y$ (Y123), because of nanoscopic network consisting of crossing RE compositional stripes. This structure is promising to act as strong pinning centers. Flux pinning enhancement due to the chemical substitution is frequently reported, and obviously optimal composition are effective for the improvement of flux pinning and related J_c [7]. It have been reported that Sm/Ba substitution would occur because ionic radius of Sm is about the same length with that of Ba, and La, Nd and Eu are also similar [8]. Therefore RE/Ba substitution would occur in SEG123 films, and it is expected an introduction of low-T_c particles into SEG123 films. In this study, in order to enhance J_c in magnetic field, we fabricated SEG123 films with different composition ratio of Sm, Eu and Gd by using PLD method and evaluated the J_c and T_c in magnetic fields.

2. Experimental procedure

SEG123, Sm123, Eu123 and Gd123 targets were made by solid-state calcination reaction method starting with mixtures of Sm_2O_3, Eu_2O_3, Gd_2O_3 (purity of 99.9%), BaO_2 (purity of 99%), CuO (purity of 99.9%) powders. The mixed powder was first sintered at 850 °C for 12 h in an isothermal box furnace. The reacted product was reground and pressed into pellets, and sintered at 900 °C for 12 h. Next, it was reground and pressed into pellets and sintered at 950 °C for 24 h and then flipped the pellets and sintered at 990 °C for 24 h. Finally, the pellets were annealed in flowing oxygen at 350 °C for 12 h.

The SEG123 films were deposited on $LaAlO_3$ (LAO) substrates by the PLD method using a KrF excimer laser (λ = 248 nm) with an energy density of 2.5 J/cm^2. We fabricated the SEG123 films with

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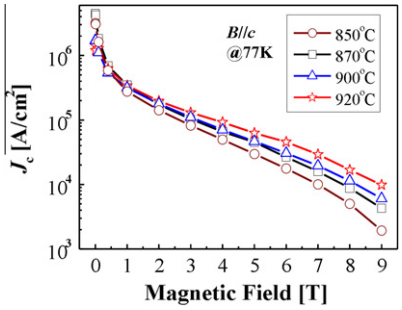

Fig. 1. Magnetic field dependence of J_c in the SEG123 at different substrate temperatures.

Sm:Eu:Gd = 1:1:1 using the SEG123 target. The composition ratio of Sm, Eu and Gd within the films was controlled by using the three targets Sm123, Eu123 and Gd123. To be specifically, first we were irradiated by 90 laser pulses to one target. Secondly replace the target and irradiated with laser pulses also 90. 90 laser pulses are equivalent to a thickness of 1 nm. For example, if we fabricated the SEG123 films with Sm:Eu:Gd = 2:1:1, using the sequence: SmBCO–EuBCO–SmBCO–GdBCO with 90 laser pulses. We repeated this procedure. The substrate was placed opposite to the targets at a distance of 60 mm. The repetition frequency of the excimer laser was 10 Hz. The pressure of oxygen during the deposition was fixed to 0.4 Torr. The PLD-SEG123 films were deposited on LAO with a thickness of 0.4 μm at 850–920 °C. The microstructure and the composition were analyzed by dynamic force microscope (DFM) and transmission electron microscopy (TEM) equipped with an energy dispersive X-ray spectroscopy (EDX) system. The crystal structure of the SEG123 films were examined by X-ray θ–2θ diffraction and ϕ-scan using the (1 0 2) plane of the SEG123. Temperature dependence of resistivity and critical current in magnetic fields were measured by standard four-probe method with physical property measurement system (PPMS).

3. Results and discussion

3.1. SEG123 films were fabricated using the SEG123 single target

All the SEG123 films on the LAO substrates showed *c*-axis orientation and cube-on-cube in-plane texture. T_c of the SEG123 films were 91.7–92.2 K. J_c of the SEG123 films in self-filed were 1.4–3.2 MA/cm^2 at 77 K.

Fig. 1 shows the magnetic field dependence of J_c in the SGE123 prepared at different substrate temperatures. J_c in self-filed were almost the same, however, J_c in magnetic fields showed a notable difference. As substrate temperatures increase, J_c in magnetic fields have been improved. But 920 °C is the upper limit of the heater equipment.

Fig. 2a and b shows DFM images of the SEG123 films prepared at 850 and 920 °C, respectively. RMS values represent the average surface roughness of SEG123 films prepared at 850 and 920 °C were 2.19 and 0.88 nm. At higher substrate temperature, surface of SEG123 films are flatter. But nanoscopic network consisting of crossing RE compositional stripes in the bulks of NEG123 and SEG123 were observed in SEG123 films. On the other hand, although the film structure shown in Fig. 2b resembles that observed in bulk NEG-123 materials, we note that the structure period is nearly two orders of magnitude higher than in the NEG-123 bulks and can therefore hardly play a similar role.

Fig. 3a shows the magnetic field dependence of J_c in the SEG123 prepared at 920 °C, the Y123 and the Sm123 films at 77 K. The SEG123 film showed high-J_c in high magnetic fields. The J_c of the

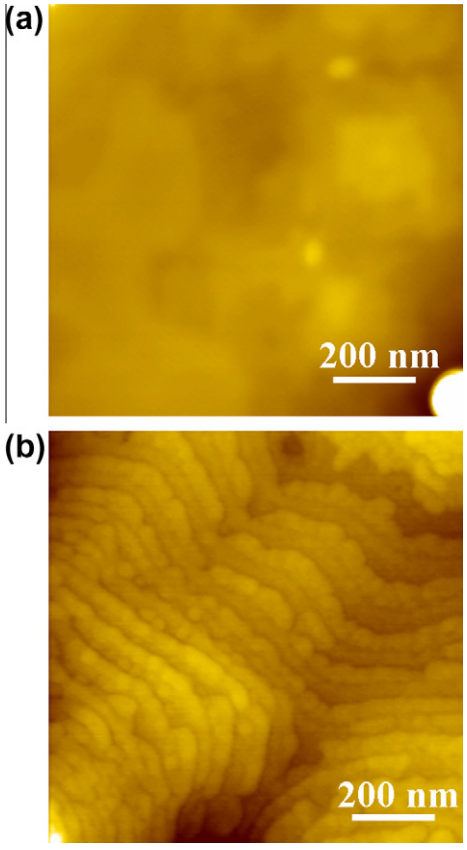

Fig. 2. (a) DFM images of the SEG123 film prepared at 850 °C and (b) DFM images of the SEG123 film prepared at 920 °C.

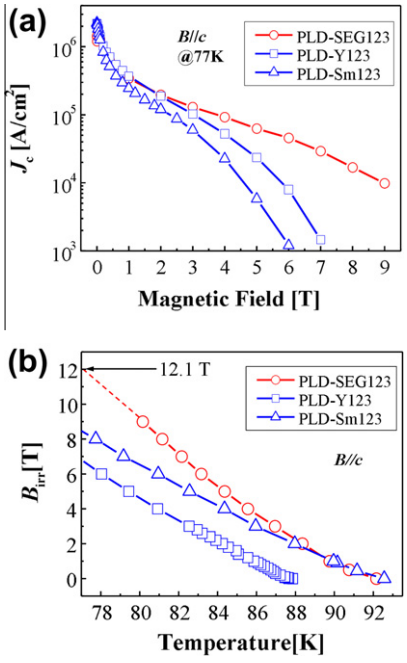

Fig. 3. (a) Magnetic field dependence of J_c in the SEG123, Y123 and Sm123 films and (b) irreversibility lines in the SEG123, Y123 and Sm123 films.

SEG123 film were 62.7 kA/cm^2 at 5 T, 9.9 kA/cm^2 at 9 T, respectively. J_c property of the SEG123 film in magnetic fields showed roughly the same with Y123 and Sm123 films in low magnetic