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Effects of RE_2O_3 (RE=Tm, Sc, Yb) addition on the superconducting properties of $ErBa_2Cu_3O_y$

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Abstract

We investigated the effects of added Tm_2O_3, Sc_2O_3, and Yb_2O_3 on the superconducting properties of sintered Er123 samples. Tm_2O_3 addition caused the least T_c degradation, exhibiting a T_c above 90 K even for 17 vol% addition. Samples with added Sc_2O_3 maintained a T_c at above 90 K up to an addition of 7.2 vol%, while Yb_2O_3-containing samples showed a monotonic decrease in T_c with increased vol% of added Yb_2O_3. Tm_2O_3-containing samples exhibited a slight increase in J_c(0.1 T)/J_c(0) and had constant J_c values even for 17 vol% addition. XRD and SEM results indicate that the Tm_2O_3 is very stable in the superconducting matrix.

PACS codes: 74.72.Dn, 74.72.Jt

Keywords: RE_2O_3, Tm_2O_3, Sc_2O_3, Yb_2O_3, Artificial pinning center

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1. Introduction

Improvement of the critical current density (J_c) of $REBa_2Cu_3O_y$ (RE123) superconductors is essential for the application of RE123 superconducting melt-textured bulk and thin films to high-performance permanent magnets or high-current-carrying wires. Introduction of artificial pinning centers (APC) into RE123 superconducting phases is a very effective technique for enhancing J_c. Significant improvements in J_c have been reported for melt-textured REBCO by adding RE_2BaCuO_5 (RE211) [1], $Y_2Ba_4CuMO_y$ [2], ZrO_2 [3], barium oxides ($BaZrO_3$ [3], $BaCeO_3$ [4], or $BaSnO_3$ [5]) to create APCs. For RE123 thin films, the J_c-B properties were also enhanced significantly by the introduction of nanometer-sized rod-shaped barium oxide into superconducting matrices [6-9]. Recently, we reported a good correlation between the stability of barium oxides in RE123 films and sintered compounds [10]. This suggests that the study of the addition of various materials into sintered samples will be of great help in the search for new APC materials suitable for high-J_c thin films in high-magnetic fields. RE_2O_3 is known to have high thermal stability and to be relatively chemically inert. However, there are few reports on the stability of RE_2O_3 in the superconducting phase [11].

In the present study, we have investigated the effects of Tm_2O_3, Sc_2O_3 and Yb_2O_3

additions on the superconducting properties of Er123 and compared their stability in the RE123 matrix.

2. Experimental

Er123 samples were prepared from Er_2O_3 (99.9%), $BaCO_3$ (99.95%), and CuO (99.99%) using a standard solid-phase reaction technique. Appropriate amounts of the reagents were thoroughly ground and calcined at 1173 K for two periods of 12 h in air, with intermediate regrinding. The resultant Er123 powder was pressed into pellets and sintered at 1233 K in air for two periods of 12 h, with intermediate regrinding. High-purity (99.9%) Tm_2O_3, Sc_2O_3, and Yb_2O_3 powders were then added to the pulverized Er123 pellets in concentrations of 1–17 vol%. The resulting powders were thoroughly ground, pressed into pellets and then sintered at 1233 K in air for 12 h. All samples were subsequently annealed in flowing oxygen at 1183 K for 12 h, cooled to 773 K with a 12 h stay, then cooled to room temperature in a furnace. The electrical resistivity of the samples was measured by a standard four-probe technique to determine their critical temperatures (T_c). J_c of the samples at 77 K was calculated from *B*-*M* curves measured by a superconducting quantum interference device (SQUID) at magnetic fields of 0-1.0 T. X-ray diffractometry (XRD) was employed to identify the phases present in the samples and determine lattice constants. The sample surfaces were characterized using a scanning electron microscope (SEM). The chemical compositions of the precipitates on the sample surfaces were determined by energy-dispersive X-ray spectroscopy (EDX).

3. Results and discussion

The T_c of the RE_2O_3-containing Er123 sintered samples are shown as a function of the amount added in Fig. 1. Samples with Tm_2O_3 added showed the least degradation of T_c, and maintained T_c above 90 K even for 17.3 vol% addition. Maintaining high T_c is comparable to $BaSnO_3$ with high stability in the superconducting phase [10]. Sc_2O_3-containing samples maintained a T_c above 90 K up to 7.2 vol% added, but showed degradation of T_c above 10 vol% added. Yb_2O_3-containing samples showed a monotonic decrease in T_c with increasing Yb_2O_3 content. These results indicate that Tm_2O_3 oxides are relatively stable in the superconducting matrix.

XRD patterns for RE_2O_3-containing samples are shown in Fig. 2. The (222) main peak of RE_2O_3 increased with increasing RE_2O_3 content for all doped samples. On the other hand, the RE123 (103) main peak decreased drastically above 10 vol% addition of Sc_2O_3 and Yb_2O_3. However, the (103) peak of Tm_2O_3-containing samples showed no distinct degradation for the addition of 17 vol%. This indicates that Tm_2O_3 addition is less liable to prevent crystal growth in RE123 than Sc_2O_3 or Yb_2O_3 addition. In further support of this conclusion, the degradation of T_c was least in the Tm_2O_3-containing samples. $BaCuO_2$ and RE_2BaCuO_5 phases were clearly observed in 17 vol% Tm_2O_3 and 10 vol% Yb_2O_3-containing samples. The formation of $BaCuO_2$ and RE_2BaCuO_5 is presumably due to the reaction of RE_2O_3 and RE123. No $BaCuO_2$ phase was observed in Sc_2O_3-containing samples, probably because Sc does not tend to form an RE123 structure [12-13]. Fig. 3 shows the lattice constants of the doped RE123 samples calculated from the XRD patterns as a function of the amount of RE_2O_3 added. The *c*-axis lattice constant of the Yb_2O_3-containing sample decreased with the amount of Yb_2O_3 added. This is likely caused by the substitution of Yb into the Er site of Er123, which is supported by the observed decrease in both the *a*-axis and *b*-axis lattice constants. On the other hand, there is no clear change in the c-axis lattice constants of the Tm_2O_3-containing and Sc_2O_3-containing samples.

Fig. 4 shows SEM images of RE_2O_3-containing Er123 samples. Fine RE_2O_3 particles, 0.5-1.0 μm in diameter, and their agglomerates were observed on the surfaces of Er123 samples with ~5 vol% addition (Figs. 4(a), (b) and (c)). Tm_2O_3 particles were clearly observed on the well-grown Er123 grain surface, as shown in Fig. 4(a). Evidence of partial-melting was observed on the surfaces with 10 vol% added Tm_2O_3 or Yb_2O_3 Er123 samples (Figs. 4 (d) and (f)). This is consistent with the XRD results. Fig. 5 shows the dependence of normalized J_c on the amount of RE_2O_3 added. J_c(0.1 T), J_c(0.5 T), and J_c(0) indicate J_c values at 0.1 T, 0.5 T, and self field, respectively. J_c(0.1 T)/J_c(0) decreased with increasing Yb_2O_3 addition. For Tm_2O_3 and Sc_2O_3 addition, J_c(0.1 T)/J_c(0) increased slightly with increasing RE_2O_3 content (Fig. 5(a)). J_c(0.5 T)/J_c(0) remained nearly constant up to 17 vol% of added Tm_2O_3, though it decreased above 10 vol% Sc_2O_3 added (Fig. 5(b)). These results suggest that Tm_2O_3 is a good candidate APC material for RE123 thin films.

4. Conclusions

The dependence of superconducting properties of Er123 sintered samples on the amount of added Tm_2O_3, Sc_2O_3, or Yb_2O_3 was investigated. Adding Tm_2O_3 resulted in the least degradation of T_c. Tm_2O_3-containing samples maintained a T_c above 90 K, showed a slight increase in J_c(0.1 T)/J_c(0), and had constant J_c values up to 17 vol%

added. $BaCuO_2$ and RE_2BaCuO_5 phases were observed in Tm_2O_3 and Yb_2O_3-containing samples, though not in Sc_2O_3-containing samples. The *c*-axis lattice constant of the superconducting phase was unchanged for both Tm_2O_3 and Sc_2O_3-containing samples, but decreased in Yb_2O_3-containing samples. SEM results indicated that Tm_2O_3 was relatively stable in the superconducting matrix. Tm_2O_3 is the most promising of the three candidate materials for creating APC's in RE123 thin films. Tm_2O_3 is a good candidate APC material for RE123 films.

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Figure captions

Fig. 1 Dependence of T_c on the amount of RE_2O_3 added to ErBCO sintered samples.

Fig. 2 XRD θ-2θ spectra for (a) Tm_2O_3, (b) Sc_2O_3, and (c) Yb_2O_3-containing ErBCO sintered samples.

Fig. 3 Lattice constants of the RE_2O_3-containing samples calculated from the XRD patterns as a function of the amount of RE_2O_3 added.

Fig. 4 SEM surface images of various RE_2O_3-containing samples. (a) 4.89 vol% Tm_2O_3, (d) 10.2 vol% Tm_2O_3, (b) 5.42 vol% Sc_2O_3, (e) 10.0 vol% Sc_2O_3, (c) 5.56 vol% Yb_2O_3, and (f) 10.0 vol% Yb_2O_3 added.

Fig. 5 Dependence of normalized J_c at 77 K on the amount of RE_2O_3 added. J_c(0.1 T), J_c(0.5 T), and J_c(0) indicate J_c values at 0.1 T, 0.5 T and self field, respectively.

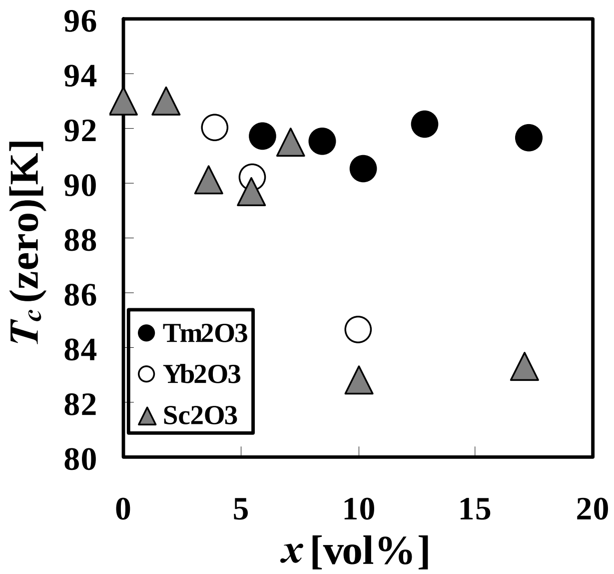


Fig. 1 BLP-1/ISS2008

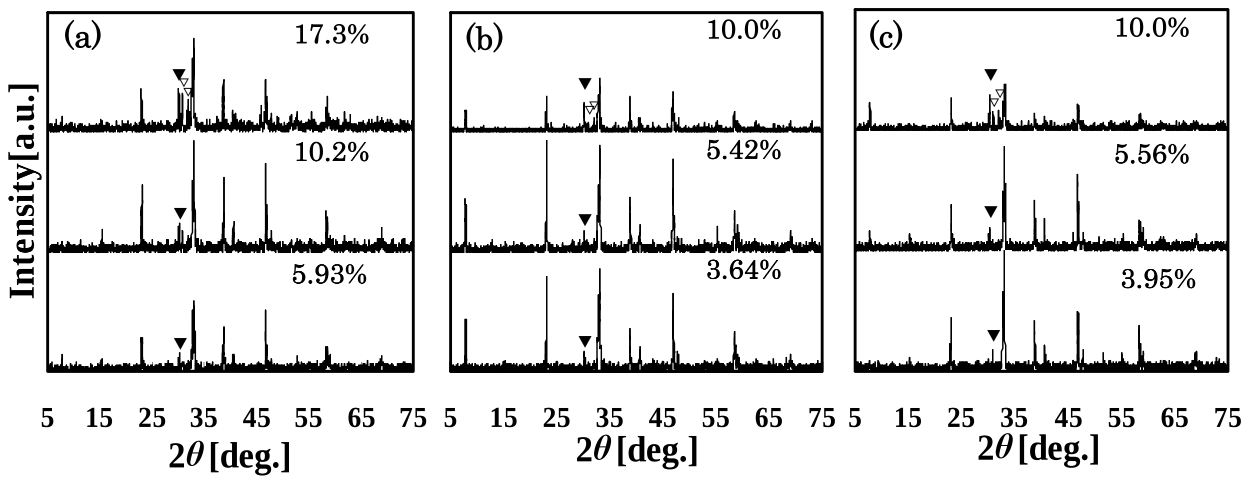
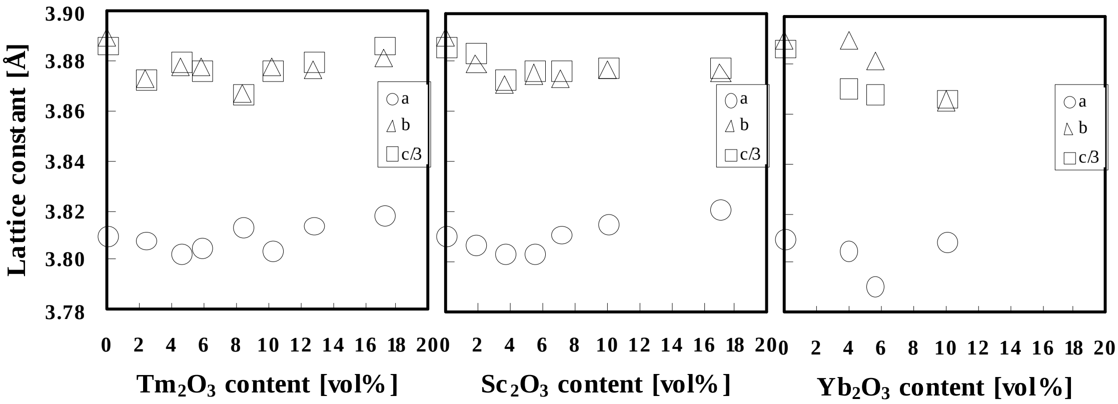


Fig. 2 BLP-1/ISS2008



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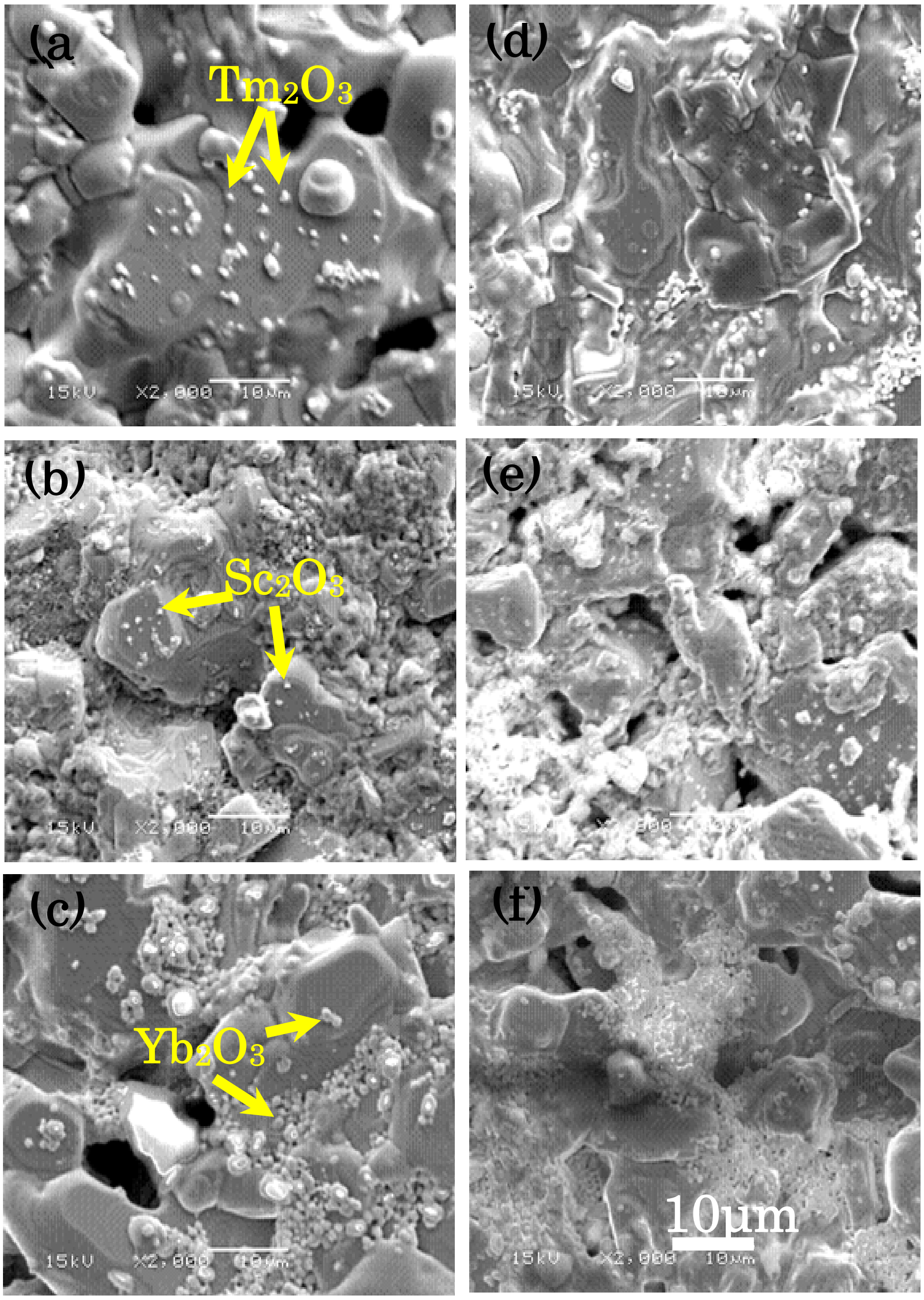

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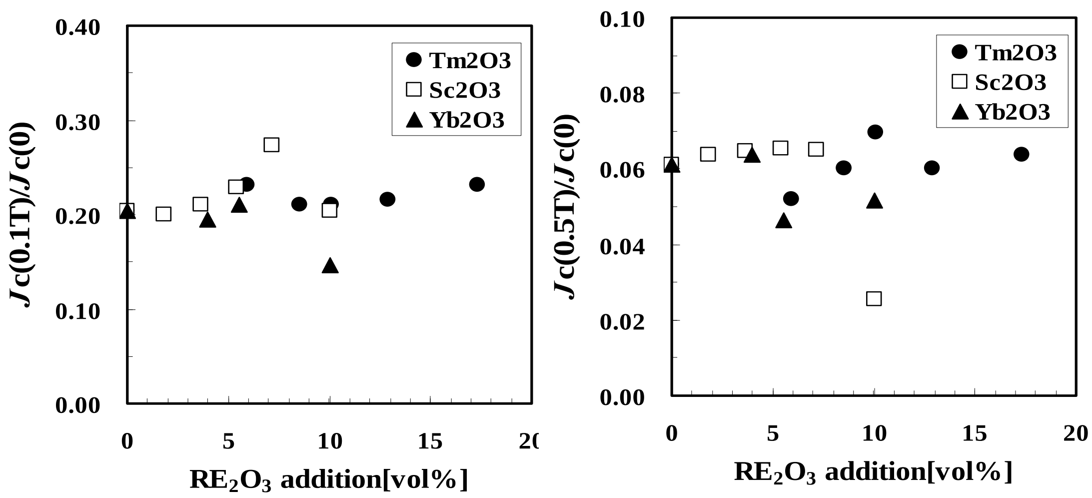

Fig. 5 BLP-1/ISS2008