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Influence of $Sm_2Ba_4CuBiO_y$ phase content on J_c of $SmBa_2Cu_3O_7/Sm_2Ba_4CuBiO_y$ nano-composites

N. Hari Babu [a,b,*], K. Iida [b], L.S. Matthews [b], Y. Shi [b], D.A. Cardwell [b]

[a] *BCAST, Brunel University, Uxbridge, UB8 3PH, United Kingdom*
[b] *IRC in Superconductivity & Department of Engineering, University of Cambridge, Cambridge CB3 0HE, United Kingdom*

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Abstract

Presence of various nano-scale $Y_2Ba_4CuMO_y$ phase inclusions in $YBa_2Cu_3O_{7-\delta}$ phase matrix are shown to improve magnetic flux pinning over wide range of magnetic fields. We first fabricate single phase of $Sm_2Ba_4CuBiO_y$ (Sm-2411) using a solid-state reaction and then introduced them into SmBCO single grains. Top seeded melt growth (TSMG) has been used to grow SmBCO single grains in air atmosphere. A significant improvement in J_c is observed, over wide magnetic fields, for single grains containing Sm-2411nano-phase inclusions when compared to that of $SmBa_2Cu_3O_{7-\delta}/Sm_2BaCuO_5$ composites. When compared to YBCO nano-composites, SmBCO composites are shown to exhibit high J_c at medium range of magnetic fields (1–2 T) at 77 K.

Keywords: Bulk superconductors; REBCO; Flux pinning; Nano-particles

1. Introduction

The effective flux pinning site size in superconductors is typically twice the size of the coherence length (a few nano-meters in REBCO, where RE is rare earth element). Flux pinning in bulk RE–Ba–Cu–O superconductors at low magnetic fields are believed to be originating from the presence of RE_2BaCuO_5 (RE-211) second phase particles, which form during the peritectic solidification process. There exists large density of defects at the interface between RE_2BaCuO_5 and $REBa_2CuO_{7-\delta}$ (RE-123) superconducting matrix. The defect density in bulk (RE)–Ba–Cu–O has been engineered partially by refining the size of RE_2BaCuO_5 second phase inclusions in the bulk matrix and by increasing their density [1,2]. RE-211 particles, however, tend to ripen during the RE-123 peritectic solidification process [3]. As a result, RE-211 particles grow typically to a size of 0.5–1 μm during peritectic solidification due to Ostwald ripening [4], unlike in thin-film fabrication process [5], and refining their size on a nano-scale level has proved generally unsuccessful, even if their initial size in the precursor body is 100–200 nm [4].

Recently Hari Babu et al. [6] have introduced $Y_2Ba_4CuUO_y$ (YBCUO) second phase particles of size 300–400 nm into the bulk YBCO microstructure. The presence of these particles has been demonstrated to contribute significantly to enhanced flux pinning in the bulk material [7,8]. It has been demonstrated that the U-element in the $Y_2Ba_4CuUO_y$ phase can be replaced with Zr, Hf, Nb, Ta, Mo, Bi, Sn and W [9,10], and the Y-element with other rare earths, such as Sm, Nd and Gd to produce a more generic phase composition $(RE)_2Ba_4CuMO_y$ (the 2411 phase). 2411 phase particles are observed to exhibit very important features both during and post-melt processing [10]. Specifically, depending on element M and rare earth element, they form nano-scale inclusions of their size ranging from 10 to 300 nm in the RE-123 matrix, are chemical stability with the Ba–Cu–O liquid, have a negligible effect on T_c of the parent superconductor and, finally, do not ripen during melt processing [11]. The distinct nature of these particles has made it possible to engineer the microstructure of (RE)BCO superconductors on the nano-scale level for the first time. In this paper, we report microstructural features of (Sm)BCO nano-composites con-

* Corresponding author at: BCAST, Brunel University, Tower A, Kingston Lane, Uxbridge UB8 3PH, United Kingdom.
E-mail address: mtsthbn@brunel.ac.uk (N.H. Babu).

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taining $Sm_2Ba_4CuBiO_y$ second phase inclusions and how the superconducting properties of these composites varies with their presence.

2. Experimental

$Sm_2Ba_4CuBiO_y$ phase powders were prepared from pure (99.9%) rare earth oxide powders, $BaCO_3$, CuO and Bi_2O_3 using a solid-state reaction process [12]. $SmBa_2Cu_3O_{7-\delta}$ and Sm_2BaCuO_5 phases were also synthesized from oxide powders using solid-state reaction. A range of SmBCO single grain nano-composites were fabricated using top seeded melt growth (TSMG) [13]. The precursor pellets containing various amount of Sm-123, Sm-211 and Sm-2411 were enriched with 2 wt% BaO_2 [14]. A generic NdBCO melt-textured crystal doped with MgO [15] of approximate size 1 mm × 1 mm × 0.5 mm was used to seed the melt process for all nano-composites. Briefly, the TSMG process involved mixing the precursor powders using a mortar and pestle, pressing the precursor powder uniaxially into a green pre-form and heating the seed-pre-form arrangement to its melting temperature (typically in excess of 1080 °C) to ensure peritectic decomposition. The decomposed samples were then cooled rapidly to just above the peritectic temperature, T_p, and then more slowly through T_p itself at a rate of less than 1 °C/h. Finally, the melt processed samples were furnace cooled to room temperature. Samples of all compositions were annealed after melt processing in O_2 gas between 400 and 350 °C for 100 h. The microstructural features of the samples were investigated by scanning electron microscopy. The superconducting transition temperature and critical current density were measured using a SQUID magnetometer.

3. Results and discussion

SEM micrographs of SmBCO single grain containing 10 wt% $Sm_2Ba_4CuBiO_y$ (Sm-2411(Bi)) phase are shown in Fig. 1(a) and (b). Both figures are for a same sample, but taken at lower and higher magnification to reveal both Sm-211 and Sm-2411 phase inclusions. It can be seen from the figure that this composite clearly consists of two different sized particles, one being <100 nm in size and the other being few microns in size. Particle size, as small as 20 nm, has been observed. EDAX spectrums were used to differentiate between Sm-211 and Sm-2411 in the micrographs. Nano-sized particles were observed to contain Bi, whereas larger particles composition is measured to be Sm_2BaCuO_5. In the case of Y–Ba–Cu–O system, Bi-containing nano-particles are confirmed to be $Y_2Ba_4CuBiO_y$ phase by comparing XRD patterns for ground single grain material containing those nano-particles and $Y_2Ba_4CuBiO_y$ phase [16]. XRD pattern for the ground pellet clearly shows that the single grain is a mixture of superconducting phase and 2411 phase.

SmBCO single grain superconductors discussed in this article are processed in air atmosphere. In order to reduce the Sm/Ba solid solution phase formation during the melt growth in air atmosphere, BaO_2 was added to the precursors prior to melt growth. The influence of the BaO_2 addition on the superconducting properties was investigated by measuring the spatiation variation of T_c using SQUID magnetometer. Small samples (1 ± 0.2) mm × (1 ± 0.2) mm × (0.5 ± 0.2) mm were cut from large grain along *a*- and *c*-axes of crystal. The onset T_c of each specimen, determined as the temperature at which the magnetic moment becomes measurably diamagnetic under 2 mT magnetic field, is plotted in Fig. 2 as a function of distance

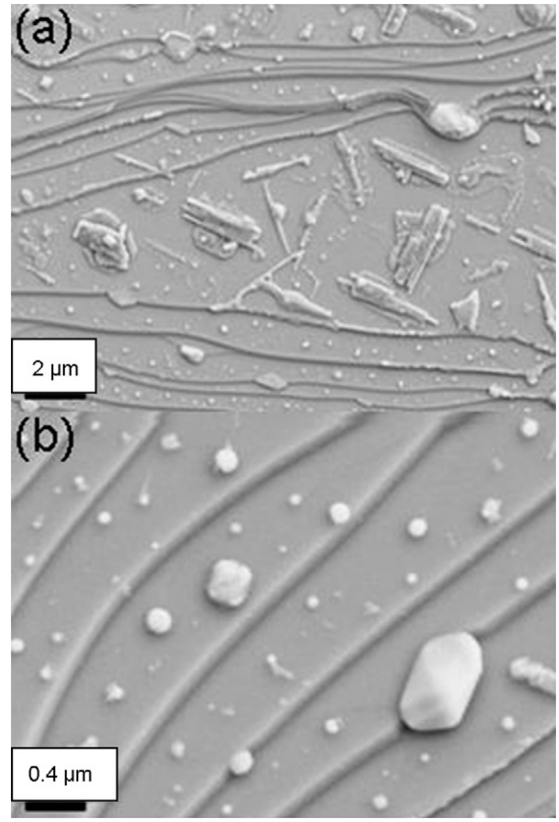

Fig. 1. High-resolution electron microscope images of unpolished SmBCO nano-composite single grains containing $Sm_2Ba_4CuBiO_y$ at two random areas revealing presence of Sm-211 (on the order of 1–2 μm) and Sm-2411 (on the order of 100–200 nm).

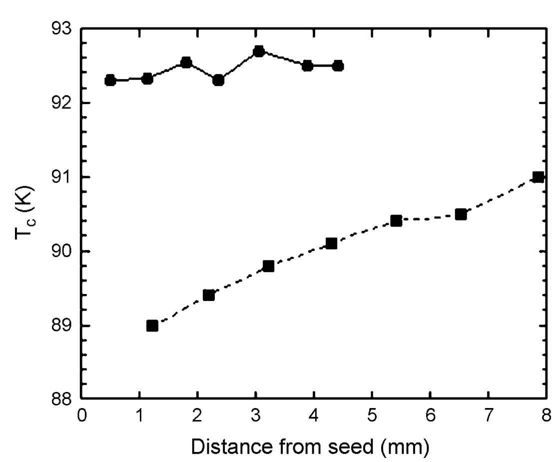

Fig. 2. Spatial variation of T_c for a single grain fabricated using TSMG with a starting composition of 90 wt% Sm-123 + 10 wt% Sm-2411 composite containing 2 wt% BaO_2. Square symbol is a typical data for single grain fabricated from a precursor composition containing no excess BaO_2 addition.