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Growth and properties of air-processed $GdBa_2Cu_3O_{7-\delta}$ superconductors with fined Gd_2BaCuO_5 and $Gd_2Ba_4CuFeO_y$ additions

Y. Zhang *, M. Izumi, Y. Kimura, Y. Xu

Laboratory of Applied Physics, Tokyo Univ. of Marine Science and Technology, 2-1-6, Etchujima, Koto-ku, Tokyo 135-8533, Japan

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ABSTRACT

We have succeeded in synthesizing a powder form of $Gd_2Ba_4CuFeO_y$ (Gd2411) in air. $GdBa_2Cu_3O_{7-\delta}$ (Gd123)/Gd_2BaCuO_5 (Gd211) precursor powders added with different amounts of $Gd_2Ba_4CuFeO_y$ (x = 0, 0.002, 0.004, 0.02) in molar ratio to Gd123 have been fabricated successfully into the form of large, single grains by the top seeded melt growth (TSMG) process. The relation between the additions amounts of Gd2411/Gd211 and critical current density (J_C) was analyzed. We found Gd2411 particles stably exist in the Gd123 matrix without degradation of superconducting properties owing to the existence of the Fe magnetic ion. The trapped field was observed to increase significantly compared with the bulk without Gd2411 additions.

1. Introduction

It has been observed that the bulk Y–Ba–Cu–O(YBCO) high temperature superconductors processed in large, single grains have 17 T trapped magnetic field at 29 K in the diameter of 2.5 cm, which is higher than any permanent magnet [1]. Thus, lots of researchers pay attention to the bulk single grain superconductors due to the significant potential of engineer application in superconductor motor and superconducting mixer *etc.* [2,3]. It is necessary to improve the critical current density J_C so as to obtain the high trapped field. Generally, second phase RE_2BaCuO_5 (RE211), and correspond to nanometer sized defect in the microstructure of the bulk are significant to achieve high J_C [4]. However, refined RE211 particles will reach to ripen or been pushed out during the RE123 peritectic solidification process [5,6].

Recently, $RE_2Ba_4CuMO_y$ (M = Nb, Ta, Mo, W, Re, Zr and Hf) [7,8] as second phase with RE211 have successfully fabricated single grain RE123 bulk. It is observed that RE2411 inclusions can embed in the superconductor matrix in nano-size and form effective magnetic flux pinning sites to increase J_C. However, there are a few reports about the contribution with the doping of M = Fe magnetic ion till now, since the magnetic ions of additions may destroy the superconductor properties of the RE123 bulk. Lau et al. observed that the Ag-sheathed Bi(Pb)–Sr–Ca–Cu–O tapes with magnetic nano-powder γ-Fe_2O_3 increase the pining strength [9].

In this paper, we fabricated single domain Gd123 bulk samples with the additions of $Gd_2Ba_4CuFeO_y$ (Gd2411) precursor include Fe magnetic ion. We focus on the magnetic properties of Gd123 bulk containing Gd211 and Gd2411 second phase inclusions.

2. Experimental

Commercial powders of Gd_2O_3 (3 N), Fe_2O_3 (3 N), BaO_2 (3 N) and CuO (3 N) were employed to synthesize Gd2411 single phase by solid state reaction method. The mixing powder was pre-reacted at 900 °C for 10 h in air twice with intermediate ground. The single phase was obtained at 1000 °C for 10 h twice in air. The Gd211 powder was prepared at 900 °C twice from oxides in air. X-ray diffraction was employed to confirm the single phase of Gd2411 and Gd211 powder. In order to reduce the particle size of Gd211, ball-milling treatment was been done for 1 h, using Y_2O_3–ZrO_2 balls. High purity BaO_2 powder was added into Gd123 matrix to suppress the form of the solid solutions due to the substitution between Ba and Gd atoms [10]. Single phase of Gd2411 and Gd211 was introduced into the Gd123 system as the second phase. The nominal composition of the bulk is Gd123 + (0.4 − x) Gd211 + xGd2411 + 0.1BaO_2 with x = 0, 0.002, 0.004, 0.02 (labeled as xGd2411), in a molar ratio. The mixed powders were pressed into pellets with 20 mm in diameter and 8 mm in thickness. The melting process of the bulk superconductors and the post-annealing in argon and oxygen gases have been reported elsewhere [2,8].

Trapped field mapping were performed at 77 K with 0.1 mm gap between the Hall sensor and the surface of sample and the

* Corresponding author. Tel./fax: +81 3 5245 7462.
E-mail address: d042036@kaiyodai.ac.jp (Y. Zhang).

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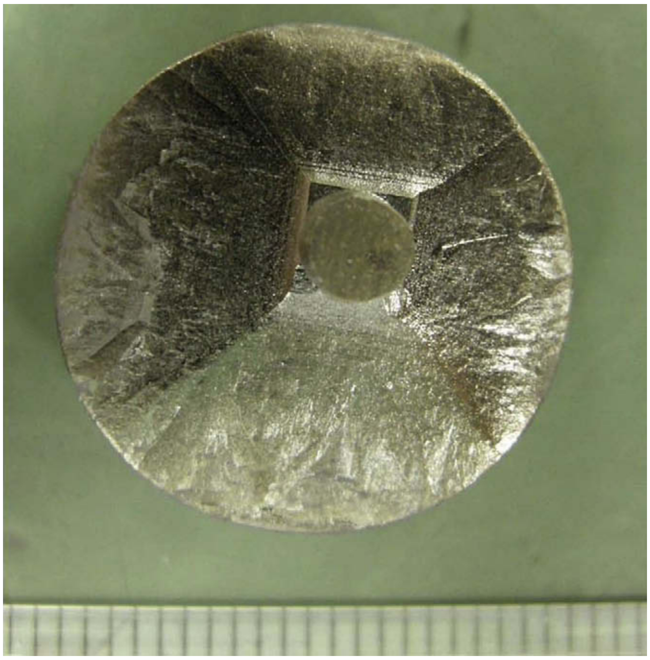

Fig. 1. Surface appearance of the superconductor bulk with 0.002 Gd2411 additions, melt-processed in air. The sample diameter is 18 mm and the thickness is 7 mm.

initially applied magnetic field was selected as 1 T. DC magnetization was measured with a Quantum Design SQUID magnetometer. To avoid the spatial distribution of superconducting properties, a rectangular slab of 2 mm × 2 mm × 1 mm was cut along *a* growth direction and *c* axis from each bulk, that is to say, one is under the seed position, another is near the boundary of the single domain. To eliminate the surface defects, the slab positioned at 1.5 mm below the seed was cut for magnetic characterization. We investigate the dc magnetization measurement under a magnetic field parallel to the *c* axis. The critical current density J_C values were estimated based on the extended Bean's critical state model for a rectangular sample [11].

3. Results and discussion

3.1. Growth of single domain and the trapped field of the bulks with and without Gd2411 additions

Fig. 1 shows the photograph taken from the top surface of the 0.002 Gd2411 superconductor bulk. They can grow into a single domain with the diameter of 18 mm and the thickness of 7 mm. The observation of microstructure including doped particle distribution by use of SEM and TEM is under progress and the result may provide a supported evidence of the effective improvement of pinning function of the present results.

Fig. 2 shows the trapped fields of (a) the bulk without Gd2411 additions and (b) 0.002 Gd2411 bulk. The applied field for both of them was 1 T with field cooling. The trapped field density arrives to 0.16 T in the bulk of 0.002 Gd2411 additions, which is higher that 0.06 T in the bulk of without Gd2411 additions. It demonstrates the Gd2411 addition enhances the trapped field of bulks. Therefore, it results in the enhancement of critical current density J_C.

3.2. Enhanced superconducting properties of bulks with different Gd2411 addition amounts

Fig. 3 shows the J_C versus applied field *B* for various compositions cut at the position near the edge of the pellets at 77 K with the magnetic field *B* parallel to *c* axis. The J_C–*B* plots do not show obvious peak effects, which is probably due to the accumulation of Gd211 particle at the edge of the single domain [12]. The J_C at

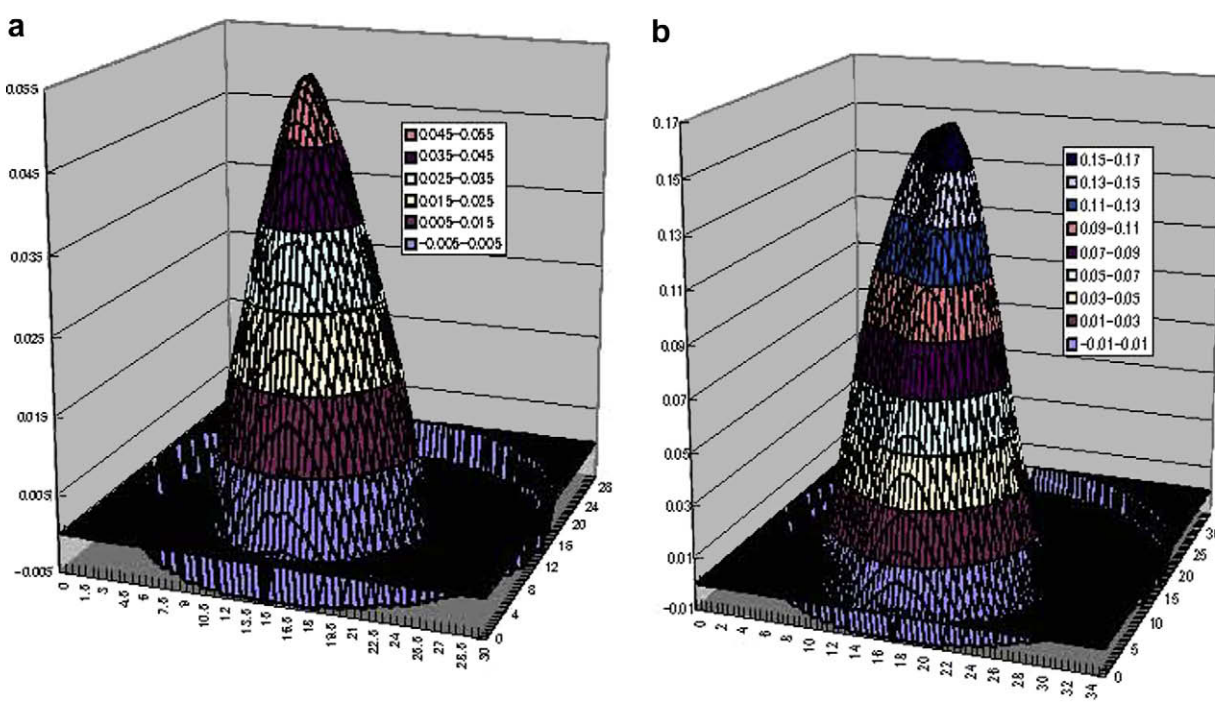

Fig. 2. Trapped field profiles on the field cooling of bulks with (a) 0.0 Gd2411 and (b) 0.002 Gd2411 at 77 K. The initial magnetic field is 1 T. Measurements is done with 0.1 mm gap between the Hall sensor and the surface of samples. The sizes of both bulks are 18 mm in diameter and 7 mm in thickness. The highest trapped field density is 0.16 T in (b).