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Magnetic field distributions of stacked large single domain Gd–Ba–Cu–O bulk superconductors exceeding 140 mm in diameter

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Abstract

We have studied the magnetic field distribution of the stacked two single domain Gd–Ba–Cu–O large bulk superconductors exceeding 140 mm in diameter, and compared with the distribution of one single domain bulk. The maximum trapped magnetic field of the stacked bulk at 65 K was 4.3 T and 5 T at the surface and at the center of two large bulks respectively, when the bulks were field-cooled in 5 T. It was found that the magnetic field could reach a longer distance and wider area by increasing the thickness. Therefore, larger and thicker bulk superconductor shows several benefits in terms of practical applications.
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1. Introduction

It is well known that the melt-processed single domain RE–Ba–Cu–O (RE: rare earth elements) bulk superconductors trap much larger magnetic field than a conventional permanent magnet. The trapped magnetic field is proportional to the critical current density J_c and its domain size. A great number of efforts have been done to increase the J_c and the domain size. The size and distribution control of RE211 non-superconducting particles embedded in RE123 superconducting matrix phase enabled us to increase the J_c values of RE–Ba–Cu–O bulk superconductor. The maximum J_c has already exceeded 10^5 A/cm^2 at 77 K in self field [1,2], which is sufficient for most applications. For promoting applications, it is desirable to increase a grain size of RE–Ba–Cu–O bulk superconductor without deteriorating the homogeneity and the high J_c values.

There are few reports on the fabrication of a large single grain RE–Ba–Cu–O bulk exceeding 100 mm in diameter [3–5]. Sawamura et al. reported the distribution of the magnetic field trapped by a large grain Y–Ba–Cu–O 100 mm in diameter [5]. However, there are few reports on the trapped magnetic field of large LRE–Ba–CuO (LRE; Nd, Sm, Eu, Gd) bulk superconductors exceeding 100 mm in diameter. LRE–Ba–CuO superconductors show higher T_c and larger J_c in high fields at 77 K than those of Y–Ba–Cu–O superconductor. Therefore, it is expected that large LRE–Ba–CuO bulk superconductors have higher potential than Y–Ba–Cu–O.

Recently, we have successfully fabricated large Gd–Ba–Cu–O bulk superconductors 143–153 mm in diameter [6–8]. In our previous reports, we have revealed that a large bulk with dimension of 140 mm in diameter and 20 mm in thickness has several benefits in terms of the practical

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applications as follows [8,9]. It was confirmed that a large amount of flux could be trapped in a large grain superconductor. In addition, the magnetic field could reach a longer distance in a large bulk compared to smaller one. The repulsive force density between the superconductor and magnet for the larger bulk was much larger than that for smaller bulk. Generally, a thin magnet has a large demagnetization field, which affects to the distribution of the effective magnetic field.

In this paper, we have studied the distribution of the effective magnetic field in thick bulk by stacking two single domain Gd–Ba–Cu–O large bulk superconductors exceeding 140 mm in diameter. The results have been compared with the data of a bulk 140 mm in diameter with a single grain. Here, the applied magnetic field was increased to 5 T by extending the cooling rod, since the applied field used in the previous study was limited below 4 T due to the leak field.

2. Experimental

In this study, two large Gd–Ba–Cu–O bulk superconductors with single domain exceeding 140 mm in diameter were used. The bulks were fabricated with melt-processing, the details of the fabrication method have been reported in our previous reports [6–8]. The bulks were machined to have the dimensions of 140 mm (No. 1, top) and 145 mm (No. 2, bottom) in diameter and 20 mm in thickness.

In order to increase the tolerance against the Lorentz force (tensile stress) induced by the interaction between the trapped magnetic field and supercurrents flowing in the bulk, the bulks were reinforced by encapsulating in a stainless steel ring 10 mm and 7.5 mm in thickness for No. 1 and No. 2 bulks, respectively, to have 160 mm in diameter. Then the space between the bulk and the stainless steel ring was filled with epoxy resin using an impregnation technique.

Fig. 1 shows the schematic illustration of the measurement system. The reinforced bulks were placed in a cryo-cooling unit using a GM refrigerator, which enables us to control the temperature. The bulks were placed on the cold head and tightly fixed to the head with a stainless steel cover. A copper plate 3 mm in thickness with a Hall probe was inserted between the stacked large bulks. Then the inner vessel was filled with helium gas in order to achieve a high uniformity in temperature. Then the vessel was further shielded with vacuum.

The bulks in a cryo-cooling unit were positioned at the magnetic center of the superconducting magnet (JASTEC, a cryogen-free superconducting magnet having a 300 mm bore diameter), and then magnetized in the presence of magnetic field. The bulks were first field-cooled in 5 T from 110 K down to 45 K. After the bulk temperature became stable, the external field was removed, and then the z-axis components of the magnetic field trapped for the bulk was measured by the following three Hall probes. First one was for the measurement of the maximum trapped

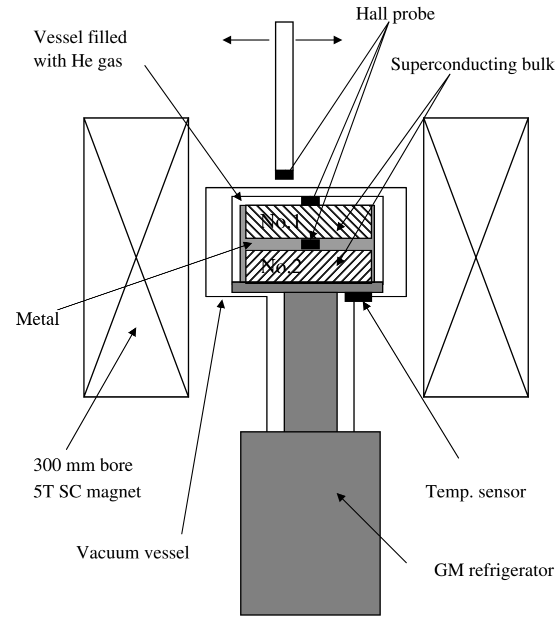

Fig. 1. Schematic illustration of the measurement system.

magnetic field at the bulk surface, in which a Hall probe was mounted on the center of the top surface (surface, gap = 0 mm) of the disk shaped bulk. Second one was for the measurement of the maximum trapped magnetic field at center of bulks (center), which was mounted in the center of a copper plate 3 mm in thickness inserted between two bulks. Third one was used for the distribution measurement of trapped magnetic field, and was scanned two dimensionally outside the vessel, in which the minimum gap, which is the distance between the Hall probe and the bulk surface, was 17 mm. Here, z-axis components of magnetic field distributions with different temperature (50–88 K) and different gaps (17–150 mm) were measured.

The magnetic field distribution generated by smaller bilks, 46 mm and 80 mm in diameters were simulated by the finite element method (FEM) analysis as follows. First, the J_c–B curves for the Gd–Ba–Cu–O bulk superconductor 140 mm in diameter at different temperature were estimated by fitting the measured trapped magnetic field distributions to the following formula,

$$J_c(|B|) = \frac{F_P}{|B| + C_1} + C_2 \times |B| \times \exp(-C_3 \times |B|).$$

Here, F_P, C_1, C_2, C_3 were constants. Then, the magnetic field distribution generated by smaller bulks were calculated by using this J_c–B curves. Details in the procedure of the calculation will be described in elsewhere [10].

3. Results and discussion

Fig. 2 shows the temperature dependence of the distribution of z-component magnetic field trapped by single and stacked Gd–Ba–Cu–O bulk superconductors along the center line at 50 K, 65 K and 77 K. The magnetic field

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