Flux pinning properties of GdBCO bulk through the infiltration and growth process

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Abstract: REBa₂Cu₃O₇₋δ (RE123 or REBCO, RE=rare earth elements, Gd, Y, Nd, etc.) bulk high temperature superconductors (HTS) have been used in lots of aspects, such as in magnetic levitation, et al., owing to the performance of high magnetic flux trapping. GdBCO superconductor bulk with 25 mm diameter has been successfully fabricated by top-seeded infiltration and growth (TSIG) method. We chose YBa₂Cu₃O₇₋δ (Y123) particles as the liquid source, which provide enough liquid sources during the growth and encourage the growth along a-b plane of GdBCO bulk. Then the existence of Y123 liquid source partly decreases the effect of the sub-grain boundaries in a-growth sectors and improves the properties of GdBCO bulk. The shape of the trapped field is close to circle. The critical current density of C2 and B2 (Jc) enhances. The superconducting transition temperature (Tc) is around 94.5K in the different position and keeps the superconducting properties. It is the important experimental data for the engineering applications of the superconductor bulk.

1. Introduction
The trapped magnetic field is 17T in YBa₂Cu₃O₇₋δ (Y123 or YBCO) superconducting bulks with a diameter of 26mm, which is higher than that in the traditional magnets [1]. The application of REBa₂Cu₃O₇₋δ (RE123 or REBCO, RE=rare earth elements, Gd, Y, Nd, etc.) bulk high temperature superconductors (HTS) in power system, such as in magnetic separation systems and magnetic levitation [2-4], is attracting the researcher owing to its high critical density (Jc) and magnetic flux trapping performance. The top seeded melt growth (TSMG) is a conventional method to fabricate single-domain RE123 bulks. While the top seeded infiltration and growth (TSIG) process is popular recently [5-8], the TSIG method resolve the followled problems, such as shape distortion, shrinkage of the final sample and leakage of the Ba₃Cu₅O₈ (035) liquid phase etc.. Zhou et al. successfully processed GdBCO bulk of 32 mm in diameter by YBa₂Cu₃O₇₋δ (Y123) liquid source through the modified TSMG method. The enough growth along the a-b plane has been allowed due to the Y123 liquid source, which depressed the accumulation of Gd₂BaCuO₅ (Gd211) particles, so as to dramatically improve the properties of the GdBCO bulk.

In this article, we successfully fabricated the single domain GdBCO bulk of 25mm in diameter with the Y123 liquid source of 5mm thickness by TSIG method. The superconductivity properties, trapped field and critical current density, of the GdBCO bulk have been studied.
2. Experimental
An initial composition of Gd123 + 40 mol% Gd211 + 10 wt% Ag2O + 0.5 wt% Pt for commercial pure powders of Gd123, Gd211, Ag2O and Pt were mixed thoroughly and then made a cylinder pellet with the diameter of 25 mm and the thickness of 12 mm. Commercially pure Y123 powders were chose to press into a pellet with the diameter of 25 mm and the thickness of 5 mm as the liquid source. The pellet of Y123 liquid source was put under the GdBCO precursor. Then we place the entire arrangement onto the Al2O3 sheet into the box furnace. The Y2O3 pellet of 3 mm in thickness was put onto the sheet, avoiding the reaction of the Al2O3 and the Y123. The temperature profile is as followed. The maximum value of temperature ($T_{\text{max}}$) was set to 1079 °C, about 70 °C above the peritectic temperature ($T_p$). And the end of the reaction temperature was set to 987 °C, about 20°C below the $T_p$. With a cooling rate of 0.3°C/h, a cold Nd123/MgO thin film was employed as a seed crystal to growth the bulk [8]. After growth, the annealing process was carried out in flowing oxygen, the sample was first heated to 450°C in 5 h and hold for 40 h, then the temperature was slowly decreased to 350°C in 140 h, 300°C in 30 h. Eventually it was cooled down to room temperature. The process has been reported elsewhere [9-10].

In order to measure the trapped magnetic flux density, we chose a 1.0 T magnetic field and cooled down the bulk to liquid nitrogen temperature. Thirty minutes later, the applied field was removed and the distribution of the trapped magnetic flux density was obtained by the Hall probe sensor. DC magnetization measurements were carried out using Physical Property Measurement System (PPMS). The small rectangular samples in a 2 mm×2 mm×1 mm size were cut from the bulk to study the DC magnetization. There are two specimens under seed position, labeled as C1, C2, and the other specimens are under the boundary, labeled as B1, B2. $J_c$-$B$ curves were deduced under the extended Bean’s critical state model [11].

3. Results and discussion
As shown in Figure 1, single domain GdBCO bulk with Y123 liquid source of 5mm thickness is successfully processed by TSIG. The Nd123 seed remains stable and there is no obvious melting phenomenon. It is clear that the diameter of the liquid source Y123 is smaller than that of GdBCO bulk. Y123 power decomposes at the peritectic temperature so as to provide the liquid source of GdBCO crystal growth [12]. Then the size of Y123 pellet shrinks as we can see. It may affect the superconducting properties of GdBCO bulk.

Figure 1. Top view of GdBCO bulk processed with Y123 liquid source in the thickness of 5mm.
Figure 2. Trapped flux density of GdBaCuO bulk processed with Y123 liquid source in the thickness of 5mm.

The distribution of the trapped magnetic flux density of the GdBaCuO bulk with the thickness of 5mm Y123 liquid source was shown in Figure 2. A circle trapped field distribution can be seen clearly, which shows the high performance of the superconducting bulk [7]. As one of the most important parameters for the practical application, the trapped field was measured and the maximum flux density value is 0.12T, which is higher than that without Y123 liquid source [9-10].

Figure 3. $J_C$-$B$ curves of the samples in the different positions of the GdBaCuO bulk processed with Y123 liquid source in the thickness of 5mm at 77 K.

Figure 3 shows the $J_C$-$B$ curves of the specimens which located at different positions B1, B2, C1 and C2. We can see that the maximum critical current density value ($J_{C,max}$) is $3.24 \times 10^4$ A/cm$^2$ for the specimen taken from C2. As is well known, the growth of c direction is fast than that of a-b plane in the melt-textured superconducting bulk. The Y123 liquid source inhibits the growth of c direction and
keeps the rich Gd211 particles in the specimen C2, which improves the superconducting properties of C2 specimen. The $J_C$ of specimen B2 is higher than that of specimen B1. We speculate that the existence of Y123 liquid source avoids the deficient of liquid source during the growth and decreases the growth of Gd211 particles at the boundary sector. The sub-grain effect has been inhibited. The Gd211 particles in the suitable size and the number increase the $J_C$ of the specimen B2.

Figure 4. Superconducting transition temperature ($T_C$) curves of the samples in the different positions of the GdBCO bulk processed with Y123 liquid source in the thickness of 5mm.

Figure 4 shows the superconducting transition temperature, $T_C$, curves under the external magnetic field. The $T_C$ is around 94.5 K, which exhibits the high quality of the superconducting bulk. The narrow transition width appears in the specimen C2 and B2, which shows the better superconducting properties. The result is corresponded with that of $J_C$. It can be obtained that the Y123 liquid source can enable the sufficient growth of the sample along a-b plane. Employing the Y123 liquid source can be effective to process the well-textured single domain GdBCO bulk in large size without the leakage of the 035 liquid phase [5, 13].

4. Conclusion

The single domain GdBCO bulk superconductor with the diameter of 25 mm has been successfully growth by the TSIG technique. The Y123 pellet with 5mm thickness solves the leakage problem of liquid source and encourages the growth along a-b plane of GdBCO bulk. So that it increases the accumulation of Gd211 particles in C2 and obviously decreases the effect of sub-grain boundaries. Thus, the properties of superconductor bulk have been improved. After detailed investigations in trapped flux, critical current density and critical transition temperature of the samples, it can be concluded that the method can be effective to fabricate single domain GdBCO superconductor bulks with large scale in the future.

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