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Effect of Li doping on the superconducting properties of single domain GdBCO bulks fabricated by the top-seeded infiltration and growth process

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ABSTRACT

Single domain GdBCO bulk superconductors have been fabricated by the top-seeded infiltration and growth process (Gd+011 TSIG) with solid phase compositions of (1-x)(Gd_2O_3+1.2$BaCuO_2$)+xLi_2CO_3, (x=0, 0.04, 0.08, 0.10, 0.12, 0.16 wt%). The effect of Li_2CO_3 doping on the growth morphology, microstructure, levitation force, trapped field and critical temperature (T_c) of single domain GdBCO bulks have also been investigated based on these samples. The results show that the single-domain GdBCO bulks can be fabricated when x is in the range of 0–0.16 wt%. The size and distribution of Gd211 particles are not influenced by the Li_2CO_3 doping in the samples. The T_c of the samples decrease from 92.5 K (x=0 wt%) to 89.5 K (x=0.16 wt%) when x increases. The decreasing trend of T_c was caused by the substitution of Li^+ on Cu^{2+} site in the GdBCO crystal. Both of the levitation forces and trapped fields of the samples increase first and then decrease with the increase of x; both of the largest levitation force of 38.5 N (77 K , 0.5 T) and the largest trapped field of 0.31 T (77 K , 0.5 T) are obtained in the sample when x=0.10 wt%. These results show that appropriate Li doping is an effective way to enhance the flux pinning force and the other physical properties of GdBCO bulk superconductors fabricated by the Gd+011 TSIG method.

1. Introduction

High temperature cuprate bulk superconductors REBCO (REBaCuO, RE: Nd , Y , Gd , Sm) can potentially be used for a variety of applications ranging from magnetic bearings [1,2], trapped field magnets [3,4], energy storage flywheels [5,6], levitated transportation systems [7–9] and superconducting motors [10] because of their high current density and ability of trapping magnetic flux.

However, the critical current density of REBCO bulk superconductors is limited by the weak links and flux creep, which were caused by grain boundaries and thermal activation, respectively. Weak links can be resolved by fabricating single-domain samples with texture microstructure. There are two popular processing methods to fabricate the single-domain REBCO bulk superconductors. One is the traditional top-seeded melt texture growth (TSMTG) process [11–19], and the other is the top-seeded infiltration and growth (TSIG) process [20–27], TSMTG approach exhibits a number of intrinsic problems, such as about 20% shrinkage of the final samples, the loss of liquid during peritectic decomposition and the presence of a large amount of porosity and regions that are free of the RE-211 phase in the fully processed sample microstructure. The TSIG method not only allows fabrication of REBCO bulk superconductors of negligible distortion in sample shape and size, but also with significantly improved microstructures [20–29]. But the traditional TSIG method is relatively more complicated and time consuming, because the conventional TSIG method needs three kinds of precursor powders, such as $GdBa_2Cu_3O_y$ (Gd123), Gd_2BaCuO_5 (Gd211) and $Ba_3Cu_5O_8$ (035). In order to improve the working efficiency and reduce the fabrication cost in the TSIG technique, we have developed the Gd+011 TSIG method, which only needs the power of $BaCuO_2$ (011) [26–28].

To prevent vortex motions, it is necessary to introduce artificial defect as flux pinning centers in superconductors, which can be done by high-energy ion irradiation [30,31] and chemical doping [32,33]. Chemical dopant as Li inserted into CuO_2 planes is complicated and allowed to increase critical current densities but to decrease the T_c. Shlyk's study showed that Li revealed higher trapped field prompting to consider Li as a more efficient addition than Ni for enhancement of flux pinning in YBCO [34]. Shlyk and Krabbes et al. also observed an increase in the trapped field in a Li-doped sample compared to Zn-doped or undoped YBCO sample especially above 65 K [35]. It indicated that doping Li acting as a spin vacancy could create a local perturbation of the antiferromagnetic correlations of Cu atoms in the CuO_2 plane and produce a spatial distribution of non-superconducting regions, which are responsible for field induced pinning in melt-

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processed YBCO. Therefore, doping Li in YBCO bulks fabricated by TSMTG became an efficient method to improve superconducting properties. However, it is not reported whether doping Li could be effective in GdBCO bulks fabricated by the Gd+011 TSIG process, in which the conventional solid phase source pellet (SPP) of Gd211 is replaced by the new SPP of (Gd_2O_3+1.2$BaCuO_2$) and the conventional liquid phase source pellet (LSP) of (Gd123+$Ba_3Cu_5O_8$) is replaced by the new LSP of (Gd_2O_3+10$BaCuO_2$+6CuO). Single domain GdBCO bulk superconductors have been fabricated by Gd+011 TSIG method in this paper. The effect of Li_2CO_3 doping on the growth morphology, microstructure, levitation force, trapped field and T_c of single domain GdBCO bulks have also been investigated based on these samples.

2. Experimental

The powder of $BaCuO_2$ (011) was prepared by solid state reaction process. Commercial powders Gd_2O_3, Y_2O_3, Yb_2O_3, CuO and $BaCO_3$ each of at least 99.9% purity and Li_2CO_3 at least 99.7% have been used as precursor powders. Solid phase compositions of (1-x)(Gd_2O_3+1.2$BaCuO_2$)+xLi_2CO_3 (x=0, 0.04, 0.08, 0.10, 0.12, 0.16 wt%) powder was uniaxially pressed into SPPs using a steel mold 20 mm in diameter, liquid phase (Y_2O_3+10$BaCuO_2$+6CuO) powder and the liquid phase support (Yb_2O_3) were uniaxially pressed into pellets using a steel mold 32 mm in diameter. The liquid phase support pellet, the LSP and the SPP were layered up together along their coaxial line. The well arranged pellets were then placed on an alumina plate with some MgO single crystals on the plate. Finally, the NdBCO seed crystal was placed on the top surface of the SPP with the ab-plane parallel to the surface, as shown in Fig. 1. All of the samples were put in a self-designed furnace with an appropriate temperature gradient, which can effectively prevent the random nucleation of REBCO grains at the edges of the samples [26,29]. The samples were first heated to 910 °C, held for 20 h, and subsequently heated to 1061 °C and held for 1.5 h to ensure complete infiltration of the liquid phase into the SPP. The samples were then cooled to 1031 °C at a rate of 60 °C h^{-1}, and finally cooled slowly to 1014 °C at a rate of 0.2–0.5 °C h^{-1} before furnace cooling to room temperature. The as grown single domain GdBCO bulks were oxygenated at temperatures ranging from 430°C to 350 °C for about 200 h under flowing oxygen to obtain the superconducting samples. The levitation forces and trapped fields were measured by using the self-designed 3D magnetic measurement system [36] and, at the same time, T_c was measured by the vibrating sample magnetometer (VSM) machine.

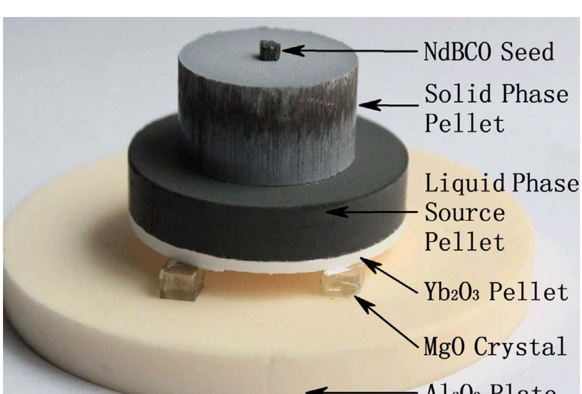

Fig. 1. The arrangement the Yb_2O_3 pellet, SPP, LSP and NdBCO seed before the Gd+011 TSIG process.

3. Results and discussion

3.1. Surface morphology

Fig. 2 is the top view morphology of the GdBCO bulk superconductors with different Li_2CO_3 additions. As we can see from Fig. 2, all the samples are nearly of single domain character, which means that single-domain GdBCO bulk superconductors can be fabricated when the Li_2CO_3 additions are less than 0.16 wt% by Gd+011 TSIG method.

3.2. Levitation force

The levitation forces of the samples were measured by the self-designed 3D magnetic measurement system. Fig. 3 shows the levitation force-distance curves between the permanent magnet (NdFeB, Φ=20 mm, B=0.5 ± 0.01 T) and the samples under the zero-field cooling (ZFC) state at the liquid-nitrogen temperature (77 K). As we can see in this figure, the levitation forces are much different for the samples with different Li_2CO_3 additions. The maximum levitation forces of each samples were achieved at the smallest separation of 0.5 mm and plotted with respect to the content of Li_2CO_3 addition in the inset of Fig. 3. It can be seen from this figure that the levitation force increases from 29.2 N to 38.5 N as the Li_2CO_3 content increases from 0 to 0.10 wt%, and then decreases from 38.5 N to 30.0 N as the Li_2CO_3 content increases from 0.10wt% to 0.16 wt%. The largest levitation force of 38.5 N is obtained in the sample with about 0.10 wt% Li_2CO_3 addition. This implies that reasonable Li_2CO_3 additions are helpful to improve the levitation force of the GdBCO bulk superconductors.

3.3. Trapped field

For trapped field measurements, the single-domain GdBCO bulk superconductors were cooled to 77 K in the presence of a 0.5 ± 0.01 T magnetic field (NdFeB, Φ=40 mm) perpendicular to the surfaces, and held for 5 min. Fig. 4a shows the 3D trapped field mapping of GdBCO bulk with 0.10 wt% Li_2CO_3 addition. We can see from this figure that the trapped field distributions of the samples show typical single-peak field profiles, which indicates that they are of single magnetic domain. The maximum trapped fields are present at the centers of the samples. Fig. 4b shows the trapped fields along the diameters of the samples. The maximum trapped field increases from 0.27T to 0.31 T as the Li_2CO_3 content increases from 0 to 0.10 wt%, and then decreases from 0.31T to 0.23 T as the Li_2CO_3 content increases from 0.10wt% to 0.16 wt%. The largest trapped field of 0.31 T is obtained in the sample with about 0.10 wt% Li_2CO_3 addition, which shows a same trend with the maximum levitation force. This implies that reasonable Li_2CO_3 additions are helpful to improve the flux pinning ability of the GdBCO bulk superconductors.

3.4. Microstructure

The microstructures of the samples were investigated by scanning electron micrographs and shown in Fig. 5. As we can see from this figure, the Gd211 particles distribute uniformly in the Gd123 matrix and there is no obvious difference among the size of Gd211 particles in different samples. It indicates that the size and distribution of Gd211 particles are not influenced by additions of Li_2CO_3.

3.5. Critical temperature

In order to make it clear what makes the difference of the levitation force and trapped field for each sample. T_c was measured with an external magnetic field of 0.01 T applied and parallel to the c-axis. Fig. 6 is the curve between temperature and normalized magnetic moment. We can see from Fig. 6 that the onset T_c decreases from 92.5K to 89.8 K as the Li_2CO_3 content increases from 0 to 0.16 wt%. The