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Comparison of $Y_2Ba_4CuBiO_y$ Nanoparticles with CeO_2 Doping on the Levitation Force of Single Domain YBCO Bulk Superconductor by TSIG Process

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Abstract

The top-seeded infiltration and growth process (TSIG) is very effective method for the preparation of $YBa_2Cu_3O_{7-x}$ (YBCO) bulk superconductors. In order to improve the levitation force of the samples, a series of single domain YBCO bulk superconductors with different ratios of nanoscale $Y_2Ba_4CuBiO_y$ (YBi2411) inclusions in the solid phase pellet is successfully fabricated by the TSIG technique on the basis of previous research. In the present work, the results of YBCO bulk superconductors with YBi2411 and CeO_2 (1 wt%) codoping system indicate that, the optimum doping of YBi2411 is 2 wt%, the size of Y211 particles is reduced compared with the samples without CeO_2 doping; the largest levitation force is about 15 N obtained in the samples with optimum YBi2411, which is about two times higher than that of the sample without CeO_2 doping. The results are very helpful for the fabrication of high quality single domain YBCO bulk superconductors.

Keywords

Nanoparticles, YBCO Bulk Superconductor, TSIG Process

1. Introduction

High temperature superconductor (HTS) has been one of the international hotspots and impotent research contents all over the world [1]. Because of the high critical temperature, strong trapped flux density, large magnet levitation force and stable suspension characteristics, the single domain YBCO superconductors have significant potential for various applications, such as high field permanent magnets, magnetic bearing, flywheel, levitated transportation systems, motors, generators, and maglev systems, etc. [2]. It is well known that the top-seeded melt texture growth (TSMTG) method is widely used to fabricate bulk superconductors with high critical current densities (J_c) at 77 K [3]. However, conventional melt processes based on the peritectic reaction have some frequent problems, such as existence of defect, the loss of liquid during peritectic decomposition, distortion, and shrinkage of the final samples. In order to solve these problems, a new technique based on the top-seeded infiltration and growth process (TSIG) has been developed by various laboratories in recent years [4]-[9]. Furthermore, the particles of Y_2BaCuO_5 (Y211) are an effective flux pinning center for single domain YBCO bulk superconductors, but the particle size is a little larger, from several micrometers to more than ten micrometer range. It is difficult to reduce the Y211 particle to the size less than 1 μm and improve the flux pinning force further, even if Pt is added to reduce the Y211 particle [1] [10] [11] [12] [13]. So effective artificial pinning centers have to be introduced to improve J_c of these materials [14]. It is found that a new kind of nanoscale inclusions $(RE)_2Ba_4CuMO_y$ (where RE = rare earth, and M = Bi, Ta, W, Mo, Zr, Hf, Ag, Sb, ⋯) has been successfully synthesized and introduced into YBCO bulk superconductor by TSMTG, the result shows that the nanoscale $(RE)_2Ba_4CuMO_y$ particles can work as effective flux pinning centers to improve J_c of the YBCO bulk superconductor [15].

In order to improve the levitation force of the samples, a series of single domain YBCO bulk superconductors with different ratios of nanoscale $Y_2Ba_4CuBiO_y$ (YBi2411) inclusions in the solid phase pellet is successfully fabricated by the TSIG technique on the basis of previous research [16]. In this paper, we report the synthesis of nanoscale inclusion YBi2411 phase powder and, the growth morphology, microstructure and levitation force of the YBCO bulks. And at the same time, the effect of 1 wt% CeO_2 additions on the levitation force of YBCO bulks has also been researched, which is necessary for the fabrication of the high performance single domain YBCO bulk superconductors.

2. Experimental

The precursor powders of Y211, $YBa_2Cu_3O_{7-\delta}$(Y123) and $BaCuO_2$(Y011) were fabricated successfully by solid state synthesis. YBi2411 powder was synthesized according to following reaction formula:

$$2Y_2O_3 + 8BaCO_3 + 2CuO + Bi_2O_3 \rightarrow 2Y_2Ba_4CuBiO_y + 8CO_2 \uparrow \qquad (1)$$

Y_2O_3, $BaCO_3$, CuO and Bi_2O_3 powders (purity 99.9%) were weighed and mixed in required molar ratio of Y:Cu:Ba:Bi = 2:4:1:1, and milled by a ball milling machine for 3 hours, then sintered at temperatures about 955˚C for 3 times with interval grinding. X-ray diffraction (XRD) experiments were done to identify the purity of the YBi2411 phase. The XRD pattern of the sintered YBi2411 powder is shown in **Figure 1**. As we can see from this figure, there is no other

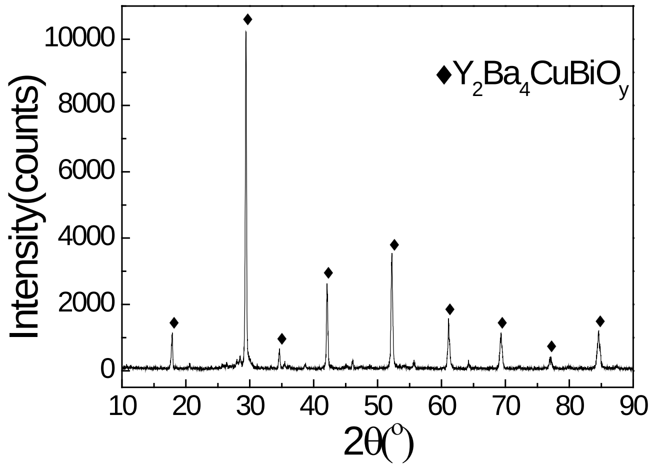


Figure 1. The XRD pattern of YBi2411 powder.

phase arising except the YBi2411 phase. This is in agreement with reference [17], which means the YBi2411 phase is of an isostructural, double perovskite cubic crystallographic structure.

2.1. Different Ratio YBi2411 Additions to Y211

The solid phase pellets were made by a well mixed powders of different ratio YBi2411 and Y211 particles. The ratio is in a weight percent of YBi2411:Y211 = x:(100 − x) (where x = 0.5, 2, 3, and 5, units: wt%) (corresponding samples are simply noted for a_1, a_2, a_3 and a_4), and the diameter of the solid phase pellets is pressed into 20 mm. The liquid phase pellets were prepared from a well mixed powders of Y123 and $Ba_3Cu_5O_8$ (Y035) powders (Y035 was mixed by the powders of Y011 and CuO in a molar ratio of Y011:CuO = 3:2), which were in a molar ratio of Y123:Y035 = 1:1. For all the samples, the liquid phase pellets is of 20 mm in diameter. Furthermore, we pressed Y_2O_3 powder into a plate of thickness of 2 mm to support the liquid phase at elevated temperature. And then the samples were put in a self-designed tube furnace with appropriate temperature gradient which can effectively prevent the random nucleation of YBCO grains at the edges of samples. Figure 2 shows the schematic diagram of a YBCO bulk sample before and after TSIG process. Each precursor sample is consist of two cylindrical pellets and layered up together along their coaxial line. The top one (green one) is the solid phase pellet, the next one (blank one) is the liquid source, and the third one (white one) is the Y_2O_3 pellet, as shown in the Figure 2(a). The precursor sample, with a NdBCO crystal seed which was made by self placed at the center of the top surface of the solid phase pellet, was heated up to 1045˚C and held for 2 h, then cooled to 1020˚C rapidly, after that, the sample was cooled to 970˚C at a rate of 0.2˚C - 1˚C /h, later the sample was cooled to room temperature at a rate of 120˚C /h. Finally, the as grown samples were annealed in flowing oxygen for 200 h at temperatures ranging from 500˚C to 410˚C, so that the as grown single-domain YBCO bulks could be of superconducting properties [16].

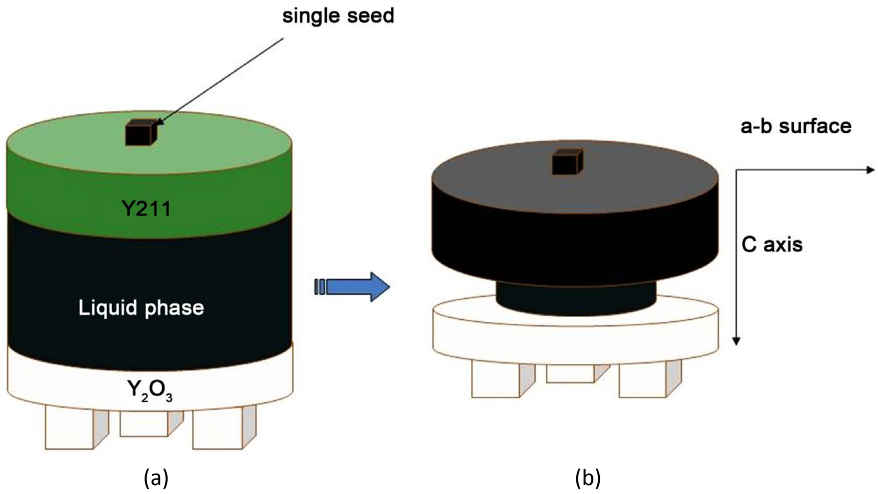


Figure 2. The schematic diagram of the sample (a: before TSIG process; b: after TSIG process). (a) Before TSIG process; (b) After TSIG process.

2.2. CeO_2 Additions to Y211 with Different Ratio YBi2411

From the references [18] [19], it is found that the CeO_2 particles doping can refine the size of Y211 particles effectively. And the optimum ratio of CeO_2 particles doping is from 0.5 wt% to 2 wt%, so 1 wt% of CeO_2 was added to the mixture of the solid phase. The ratio of the solid phase is in a weight percent of YBi2411:Y211:CeO_2 = x:(100 − x):1 (also where x = 0.5, 2, 3, and 5, units: wt%) (corresponding samples are simply noted for b_1, b_2, b_3 and b_4). The liquid phase pellets were also mixed by the powders of Y123 and Y035 in a malor of Y123:Y035 = 1:1. Next assembly way of all the pellets is as the same as described in 2.1 section, as shown in **Figure 2(a)**. Finally, the precursor samples were heated and annealed in flowing oxygen, which could be the YBCO bulk superconductors.

Then the magnetic levitation force of all the YBCO bulks was measured in the self-designed magnetic levitation force device [20]. And meanwhile, a scanning electron microscope (SEM) was used to observe microstructure of the YBCO bulk superconductors.

3. Results and Discussion

Figure 3 is the top view morphology of the YBCO superconductors fabricated by TSIG technique. As we can see from the samples of a_1, b_1, c_1 and d_1 in **Figure 3**, the morphology of samples indicates that YBCO crystal can grow from the NdBCO seeds for the samples and form as a single-domain of the whole samples surface except a tiny flaw. We can found that the optimum morphology is as sample c_1, the ratio is 3 wt%, which has not the random nucleated and is the best single-domain one.

As we can see from the samples of a_2, b_2, c_2 and d_2, which are doped with 1 wt% CeO_2 and different ratio of YBi2411, the surface macrostructure of samples is indicated that the shape of the grown crystal is different for the samples with

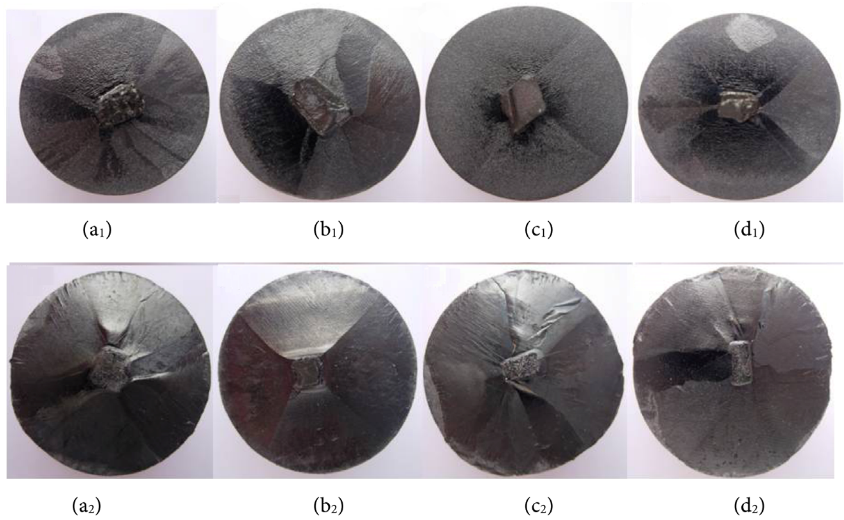
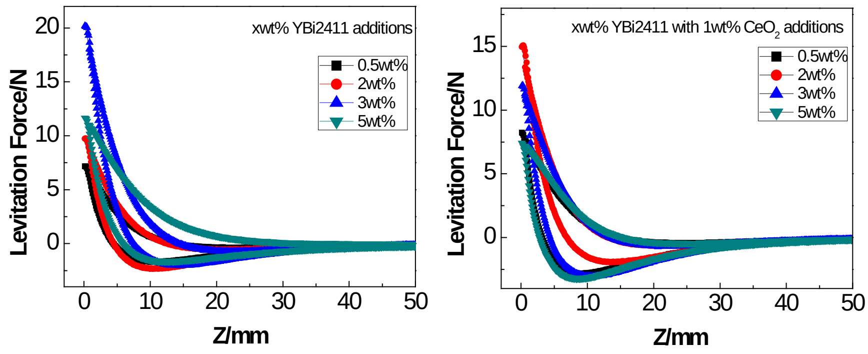


Figure 3. Top view of the YBCO bulk superconductors. (The above four samples are fabricated by different ratio YBi2411 additions, (a_1) x = 0.5 wt%, (b_1) x = 2 wt%, (c_1) x = 3 wt%, (d_1) x = 5 wt%; the below four samples are fabricated by 1 wt% CeO_2 with different YBi2411 addtions, (a_1) x = 0.5 wt%, (b_1) x = 2 wt%, (c_1) x = 3 wt%, (d_1) x = 5 wt%.)

different YBi2411 additions. When $x \leq 2$ wt%, the YBCO crystal can grow up to the whole samples and forms as a single-domain, as shown in **Figure 3(a_2)** and **Figure 3(b_2)**; when $x > 2$ wt%, the YBCO crystal cannot grow up to the single domainand there are some random nucleated YBCO grains at the edge of the samples, as shown in **Figure 3(c_2)** and **Figure 3(d_2)**. And from these four figures, the optimum YBi2411 nanoparticles doping is 2 wt%. So we can know that the best ration of the YBi2411 nanoparticles additions is reduced compared with the samples without CeO_2 doping.

Figure 4 is the levitation force-distance (Z), curves between the magnet and the samples of YBCO superconductors, which were measured at 77 K under zero-field cooling state. It is found from **Figure 4(a)** that the levitation force is much different for the samples with different YBi2411 particles additions, the levitation force increases from 7.1 N to 17.8 N as the YBi2411 additions x increases from 0.5 wt% to 3 wt%, and then it decreases from 17.8 N to 11.6 N as the YBi2411 content x increases from 3 wt% to 5 wt%. The largest levitation force is obtained in the sample with about 3 wt% YBi2411 nanoparticles additions. It implies that the reasonable particles of YBi2411 additions are helpful for us to improve the levitation force of the YBCO bulk superconductor. Similarly, the samples, which are doped to different YBi2411 particles with 1 wt% CeO_2 additions, levitation force of which were also measured. From **Figure 4(b)**, we can see that the largest levitation force is about 15 N, and the force is obtained in the sample with 2 wt% YBi2411 additions, which is much larger than the sample (2 wt% YBi2411 nanoparticles additon) without CeO_2 doping. The comparison diagram was exhibited as shown in **Figure 5**. From this figure, it is found that when YBi2411 content x is 0.5 wt% and 2 wt%, the levitation force of the samples which were doped 1 wt% CeO_2 are much larger than those without CeO_2.



(a) (b)

Figure 4. Levitation force of the samples ((a): different additions of YBi2411 to Y211; (b): different ratios of YBi2411 with 1 wt% CeO_2 to Y211).

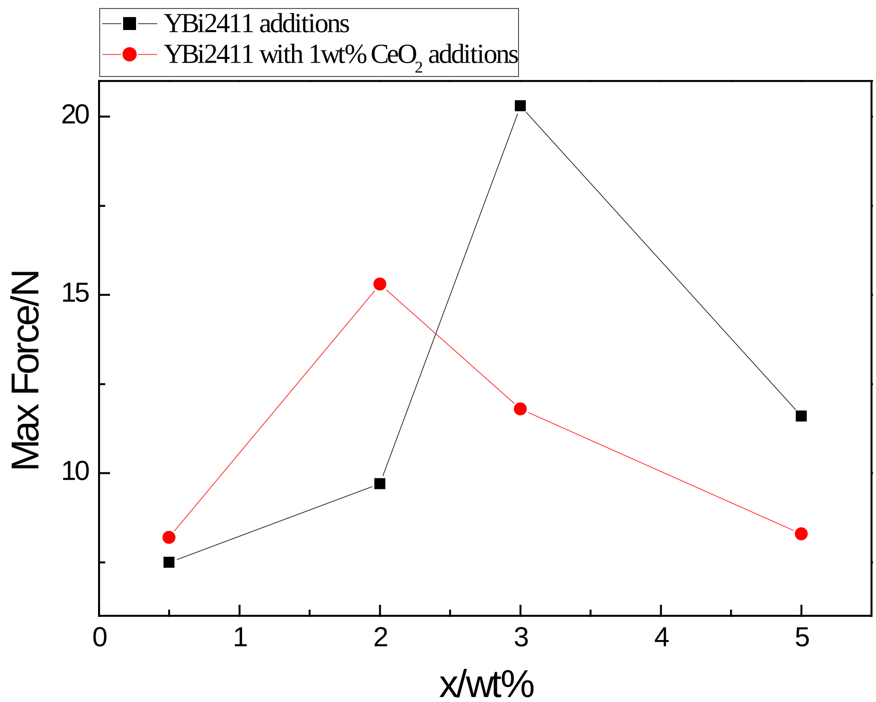


Figure 5. The comparison diagram of the max levitation force.

This is due to that the CeO_2 particles doping can effectively refine the size of Y211, which added more flux pinning center into the superconductor samples. Consequently, the levitation force can be increased effectively. On the contrary, the levitation force is much different when x is increased from 3 wt% to 5 wt%. The levitation force of the samples which were doped 1 wt% CeO_2 are rapidly down compared to those without CeO_2, and the force were fallen by half. For instance, the levitation force is about 20 N when 3 wt% YBi2411 doped, but it is rapidly down to 7 N when 3 wt% YBi2411 with 1 wt% CeO_2 doping. This result indicates that, 1 wt% CeO_2 doping can make reduction the amounts of YBi2411 particles for fabricating high performance YBCO supercondcutors.

Figure 6 shows the Quanta 200 scanning electron micrographs (SEM) of the

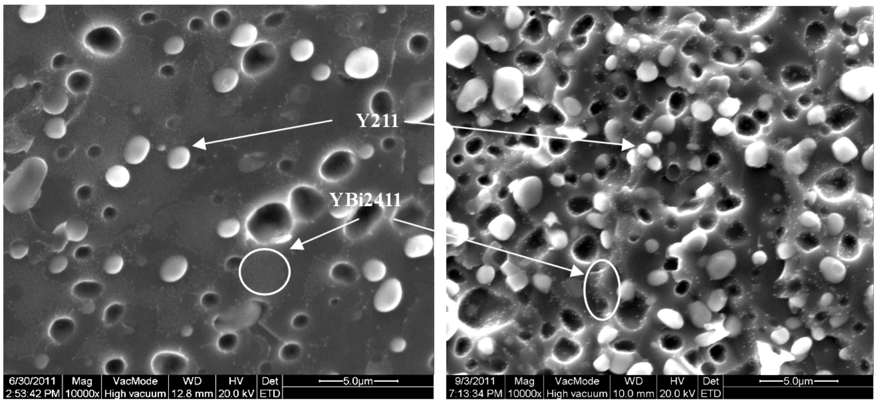


Figure 6. Scanning electron micrographs at a/b plane of the YBCO bulks. (a) 3 wt% YBi2411 additions to Y211; (b) 1 wt% CeO_2 with 2 wt% YBi2411 additions to Y211.

cross-sections of the YBCO bulk samples. As we can see from these two figures, there are two kinds of particles distributed in the YBCO matrix, one is Y211 light grey particle, which is distributed in the samples, and the size of these particles is in the range from 2.0 μm to 5.0 μm. The other is the YBi2411 particle, and it is also near uniformly distributed in the samples. Furthermore, the width of the YBi2411 particles is in the range from 100 nm to 500 nm, which is indeed much smaller than that of the Y211 particles. From these figures, it is clear that the YBi2411 phase remains stable during the solidification process, but the size of these particles is quite different. The average size of the YBi2411 particles is nearly about 300 - 500 nm when 3 wt% YBi2411 additions, which is not uniformly distributed in the sample, as shown in **Figure 6(a)**, and it is found that YBi2411 particles will be accumulated together and formed the platelike structure in some regional. On the contrary, it is different when 1 wt% CeO_2 doped. It is found that the sizes of the YBi2411 particles are much smaller than the former one, and on average it is about 100 nm. As shown in **Figure 6(b)**, not only the distribution of the YBi2411 particles is scattered, but also the Y211 particles is. Consequently, the equably dispersed of the YBi2411 particles are highly increased the total area of the YBi2411/Y123 superconductivity interface, and also greatly increased the area of YBCO superconductors, which lead to an addition of magnetic flux pinning force and levitation force of the samples with CeO_2 addition. This is in agreement with the levitation force as shown in **Figure 5**.

4. Conclusion

Single domain YBCO superconductor bulks have been fabricated by TSIG process with different ratio YBi2411 nanoscale particles additions. We have investigated the effect of the single domain YBCO bulk superconductors by TSIG process. It is found that 2 wt% YBi2411 particles with 1 wt% CeO_2 doping can fabricate the larger levitation force of YBCO superconductor bulk, which has the significant influence to the development of application of high temperature superconductor REBCO in the future.

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