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The homogeneity of levitation force in single domain YBCO bulk

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Abstract

The pellet homogeneity of levitation force versus the position in comparison to the seed or to the top surface has been studied in the entire volume of a single domain $YBa_2Cu_3O_{7-\delta}$ bulk sample processed by the top-seeded melt texturing growth (TSMTG). It is found that the levitation forces increase and peak at a depth of 3 mm from the top of the sample at liquid nitrogen temperature. In other words, the second disk has the largest levitation force density. The phenomenon can be interpreted by the interaction between the microcracks or pores produced by crystal growth and the oxygenation. We propose a model in which Y211 particles distribution leading to microcracks and pores reduces the effective induced shielding current loops (ISCL) and increases the perimeters of ISCL. This corresponds to a decrease in the grain size and results in greatly reduced levitation forces of the bottom of the bulk. From the research, we know that the density of the YBCO bulk is also an important parameter for the levitation properties. The result is very attractive and useful for the fundamental studies and fabrication of TSMTG $YBa_2Cu_3O_{7-\delta}$ bulk.

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Keywords: Melt textured $YBa_2Cu_3O_{7-\delta}$; Levitation force; Microcrack and pore; ISCL

1. Introduction

There has been much effort in applying high-temperature superconductors (HTS) to practical uses since their discovery. Top-seeded melt texturing growth (TSMTG) [1,2] is one of the most important and effective ways to fabricate high quality YBCO bulk superconductors with a high levitation force at 77 K. The high levitation force of well textured YBCO bulks has attracted many scientists to work on its applications, such as magnetic bearings [3,4], flywheels [5] and levitated transportation systems [6]. For a TSMTG single-domain YBCO bulk superconductor, it is known that the levitation force is dependent on many parameters, such as the critical current density and grain radius, grain orientation, thickness of the sample and the cooling temperature [7].

But for a given permanent magnet (NdFeB with a surface field of 0.5 T), it is known that the same levitation force can be obtained from both the YBCO bulk (30 mm) and the same YBCO bulk with a small hole (8 mm) in the center parallel to the *c*-axis [8], indicating that the outer surfaces are mainly responsible for the levitation force. So it is important and meaningful to study the homogeneity of levitation force in the YBCO bulk. However, all the results on the levitation force of YBCO, including both experimental and theoretical descriptions, have been taken from the entire volume or some rectangular dimension of the single domain YBCO bulk samples. Up to now, we cannot find any work focused on the homogeneity of levitation force in the bulk superconductor [9]. The identification of the effect of the YBCO bulk local levitation force is not only of interest for fundamental studies, but is also very important for fabrication.

In the present paper, we investigate the homogeneity of levitation force in the entire volume of the single domain bulk samples. In fact, the issue is to know why the quality

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of the sample deteriorates at the bottom. In order to analyze the homogeneity of levitation force in the whole body, the homogeneity levitation force and microstructural features, as well as the critical current density are examined as a function of the position in the bulk.

2. Experimental details

2.1. Sample preparation

Samples with nominal compositions of $YBa_2Cu_3O_{7-\delta}$ (Y123) and $Y_2BaCuO_{7-\delta}$ (Y211) were fabricated through a standard solid-state reaction technique using high-purity Y_2O_3, $BaCO_3$ and CuO. Y123 and 30 mol% Y211 powders with additive 0.5 wt% CeO_2 were mixed for 2 h in an agate ball mill. The resultant mixed powders were pressed into a pellet (20 mm diameter and 10 mm height) under the pressure of 100 MPa. A melt textured seed of Sm123, cleaved parallel to the *ab* plane, was placed at the center of the pellets top surface before the texturing process. A vertical tube furnace was used for TSMTG processing. The seed pellet, which was put onto an Al_2O_3 plate with a Y_2O_3 substrate on the top surface, was put into a vertical furnace with a temperature gradient in the vertical direction. The samples were quickly heated up to 930 °C and held for 5 h for homogeneous melting. After this, the samples were then rapidly heated to 1045 °C, held for 0.5 h at this temperature, after cooled to 1010 °C, later cooled to 970 °C at a rate of 0.2–1 °C h^{-1}, and then cooled to room temperature naturally. The as-processed YBCO pellets are of the non-superconductive tetragonal phase. Therefore, a post oxygen annealing is necessary to get the superconducting orthorhombic phase. The well-textured samples were then oxygenated at 500 °C for 150–200 h under flowing oxygen.

2.2. Experimental measuring

Fig. 1 shows an optical photograph of the single-domain YBCO bulk used in this study. The grain orientation of the sample was investigated by X-ray diffraction (XRD), optical microscopy (OM) and scanning electron microscopy (SEM). The results indicate that the YBCO sample is a single-domain structure with *c*-axis perpendicular to its top surface (results not shown here).

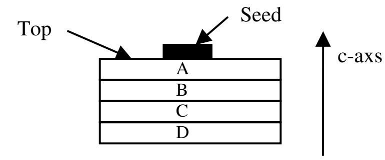

Fig. 2. Schematic illustration showing how to cut the sample. The thickness of the saw is 0.3 mm.

In order to investigate the homogeneity of the bulk pellet, we have isolated for zones from the sample, as illustrated in Fig. 2. The upper zones correspond to the dense area, the lower zones, to the porous one. The choice of the thickness of cutting was made so that the four zones have the same volume. All disks are of the same thickness of about 2 mm, denoted A, B, C and D, respectively, from surface to bottom. All the levitation force measurements were performed with a permanent magnet ($\varphi = 30$ mm) with a surface field of 0.5 T under zero field cooled at liquid nitrogen temperature in experiment. The maximum levitation force measured in this experiment was taken at the smallest gap (0.5 mm) between the two nearest surfaces of the sample and the magnet. The distance between the samples and the permanent magnet is measured precisely by a displacement sensor.

In order to analyze the Y211 particle and local critical current density distribution in the whole body, similar single-domain materials were sectioned into four smaller rectangular samples, denoted (a), (b), (c) and (d), respectively, as indicated in Fig. 3. After simply polishing all the samples, magnetic hysteresis curves were measured from −6 T to 6 T by a commercial Quantum-Designed magnetometer (PPMS), with the field aligned along the *c*-axis. Critical current densities were calculated from magnetic hysteresis loops using the extended Bean model. The morphology of four regions ((a), (b), (c) and (d)) was also investigated by scanning electron microscopy (SEM) as depicted

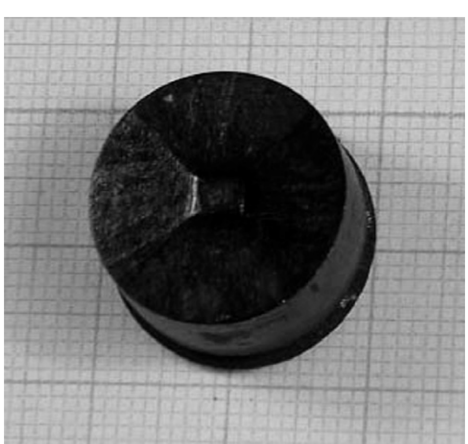

Fig. 1. Optical photograph of a single-domain YBCO bulk.

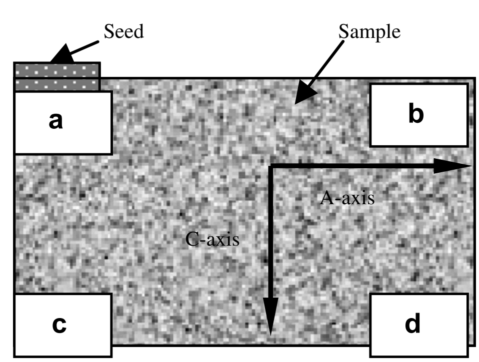

Fig. 3. Schematic illustration of SEM photograph of the YBCO bulk.