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Pulsed-Field Invasion to HTS Bulk Magnets Grown from Two Seeds with Varied Seed-Crystal Positions and Numbers

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Abstract

The flux-invasion behavior into the melt-processed Y-Ba-Cu-O bulk magnets were precisely measured and analyzed during and after their pulsed-field magnetization processes operated at 30.6 K. The materials were fabricated as the bulk monoliths grown by adopting two seed-crystals, or shifting the seed-crystal positions from the centre of the sample surface, which exhibited the magnetically single-domain distributions. Although the performances of the trapped flux density after activations showed no obvious differences, the flux started invading into the sample bearing two seeds obviously at lower fields than those of normally-grown isotropic crystal. Since the flux penetration behavior were thus clearly different between the samples with the structure grown from two seeds and uniformly grown samples with a seed crystal, it is suggested that the structure results in an effective magnetizing method with less heating than those of conventional samples, which results in the higher performance of field trapping in the bulk magnets than usual.

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Keywords: Bulk magnet; trapped field; seed crystal; pulsed-field

1. Introduction

The high temperature superconducting oxide materials (abbreviated as HTS) fabricated by melt-processes act as the trapped-field magnets what we call “the bulk magnets” [1-3]. To activate them, some investigations have been

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conducted on the pulsed-field magnetization (PFM) method, which is characterized as a compact process in comparison with the field cooling (FC) method [4, 5]. The fact that the trapped fields by the PFM processes are inferior to those by FC is attributed to the heat generation caused by the motion of the applied magnetic flux [6, 7].

It is well-known that the melt-processed bulk magnets show the heterogeneous microstructures according to the presence of non-superconducting Y_2BaCuO_5 (Y211) precipitates which contribute to the enhancement of the J_c values [8]. The magnetic flux motions in the superconducting materials are strongly affected by the distribution the Y211 particles. In addition to the temperature controlling [9] and successive PFM [10], Fujishiro *et al.* has succeeded in obtaining the highest performance of 5.2 T with the precise analysis on the trapped-field distributions [11, 12]. The trapped-field distributions which remain in the bulk magnet before the following activation affect the magnetic flux motion in the sample and resultant field-trapping [13].Therefore, it is definitely important to clarify the behaviors of the invading flux into the bulk magnets during the PFM processes in order to enhance their field-trapping ability. In this paper, the bulk magnets bearing the structure grown from two seeds were fabricated so as to examine how the field-penetration occurs when the intense magnetic pulsed-fields are applied to the samples in their superconducting states. We attempt to examine the various field-trapping properties and the flux motions through the discussions on the experimental data of the trapped-flux densities.

2. Experimental

2.1. Sample preparation and structural analysis

The $YBa_2Cu_3O_{7-\delta}$ (Y123) and Y211 powders with the mean size of 1 micron meter (Toshima Seisakusho Co.) were mixed in the zirconia mortar with the certain ratios with 1 wt% CeO_2 addition and pressed into the pellets with dimensions of 20 mm in diameter and 10 mm in thickness. The nominal content of Y211 was chosen as 28.5 mol%. The precursors were heat-treated in the cold seeding method with the Nd-Ba-Cu-O thin films on the MgO crystal (THEVA Co.). The precursors were heated to 1050 ^oC, and then gradually solidified from the peritectic temperature with the cooling rate 0.25 ^oC/h so as to let the crystal grow large. The post annealing was operated in the temperature range of 500 – 300 ^oC for 167 hours in the flowing pure oxygen atmosphere.

2.2. Pulsed-field magnetization procedure

The total system structure is illustrated in Fig. 1(a) with the electrical circuit with a condenser bank bearing the capacitance of 120 mF (Nihon Denji Sokki Co., SBV-10124), a shunt resister, and an oscilloscope [14].

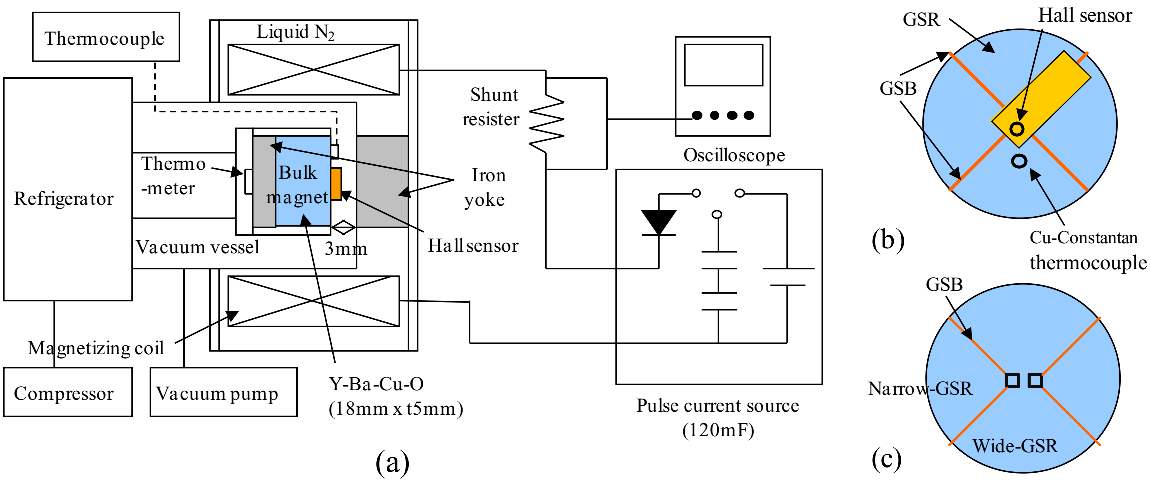

Fig. 1. Experimental set up for pulsed field magnetizing method (PFM)

Sample	#1	#2	#3	#4	#5	#6
Seed crystal	Single centered	2.5mm displaced	twin	twin	twin	twin
growth time	80h	80h	80h	80h	60h	80h

Fig. 2. Y-Ba-Cu-O Bulk Superconductors grown from various positions and numbers of seed crystals

The system was mainly composed of a cryostat with the size of 68 mm in diameter, a GM refrigerator (AISIN SEIKI CO., GR-103), which cooled the bulk magnet to 30.6 K in the vacuum chamber. A compressor to supply the pressurized helium gas to the cooler, and a temperature controller were connected to the system. The intense magnetic fields were generated by feeding currents from the condenser bank to the pulse coil, which activates the bulk magnet. The pulse coil is dipped in the liquid nitrogen vessel to reduce the resistance by cooling it to 77 K [12]. The coil constant is 0.925 mT/A. The iron yokes are coupled with the bulk magnet to attract and lead the magnetic flux into the sample during the field application. As shown in Fig. 1(b), a Hall sensor (F. W. Bell, BHT 921) was attached just at the centre of the sample surface so as to measure the flux motion during the PFM operation. A fine Cu-Constantan thermocouple, the size of which is 0.07 mm in diameter, was glued on it at the position in the growth sector region (GSR). Figure 1(c) shows the positions of two seeds on the sample surface with the positions of the growth sector boundaries (GSBs). We applied various magnitudes of single pulsed-fields ranging from 2.8 to 5.0 T with uniform rise time of 10 ms, and measured the time evolution profiles of the magnetic flux density during the PFM periods, and the resultant trapped magnetic flux densities after the processes.

3. Results and discussions

3.1. HTS bulk magnets grown from two seeds

The topside-views of the bulk magnet samples fabricated with various conditions are shown in Fig. 2. The sample size is 15 mm in diameter. One sees the apparent GSBs, which indicate their characteristic "X-shape". We note that #1 sample is the conventional single-seeded sample, #2 is the sample bearing the single-seed whose position was displaced 2.5 mm distance from the centre of the surface, and #3 – 6 are two-seeded crystals. The GSB lines for #3 – 6 samples divide the GSR into the narrow and the wide portions along the direction parallel to the rows of the seed crystals and normal to them, respectively. Since the neighbouring corners of the seeds draw no GSBs, we defined the direction along the row of seed crystals as narrow side of the GSR (abbreviated as Narrow-GSR) and as wide side which is normal to it (Wide-GSR), as shown in Fig. 1(c).

3.2. Trapped-fields in the bulk magnets after PFM process

The resultant trapped magnetic flux densities measured at the center of each pulsed-field application are shown in Fig. 3. We must emphasize that every profile shows a peak of trapped-field and following gradual decrease. This is attributed to the heat generation which occurs during the flux invasion [7]. The highest trapped field of 2.18 T was obtained for the sample #1. The profiles are apparently distinguished as two groups. As for the single seeded samples, the magnetic flux never reaches the center of the sample until 3.5 T (#1 and 2), whereas the samples #3 – 6 easily allow the flux to invade the samples when the field of 3 T is applied. This implies that the grain growth

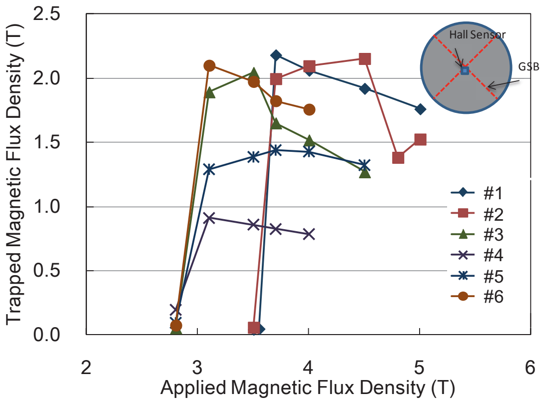

Fig.3. Trapped flux densities in bulk magnet samples with various positions and numbers of the seed crystals

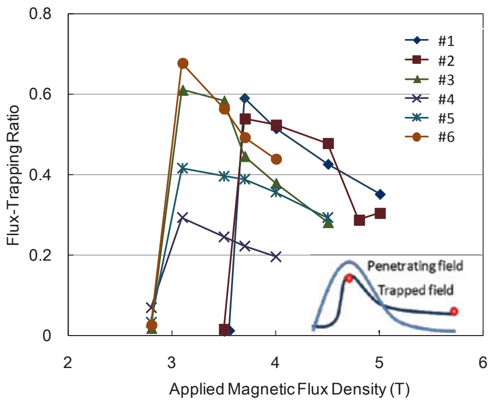

Fig.4. Trapped Flux-Trapping Ratios of the invading magnetic flux measured at the center point

structure grown from two seeds must affect the different behaviors on flux invasion. Figure 4 shows the data of flux-trapping ratios, which is defined as a quotient of resultant trapped field (abbreviated as trapped field) divided by the maximum of field penetration (penetrating field) measured in the time evolution profiles in PFM processes, as shown in the inset of Fig. 4. The data of the ratios for #3 and #6 exceeded those of #1 and #2. This means the improvement in the flux trapping behavior in the processes. Since we know that the flux penetration happens preferentially in the GSR to GSB, in this experiment, it is inferred that the pulsed magnetic flux has invaded the sample through the easier paths in the area of Wide-GSR than the harder ones in Narrow-GSR. The magnetizing operation at the lower field than usual leads the less heat generation during the process. The fact must suggest the high field trapping performances with less degradation on J_c than uniformly-grown single domain bulk magnets.

4. Conclusion

The field-trapping behavior of the Y-Ba-Cu-O bulk magnets grown from two seeds with various conditions of seed crystals was evaluated with respect to the trapped flux density during and after PFM processes. The magnetic flux invades the two-seeded samples at the lower field than those of usual single-seeded crystals. The different structures between Narrow- and Wide-GSRs which were introduced by two seeds in controlling the crystal growth directions affected the preferential flux invasion behavior. The results clearly suggest an activation method with less heat generation for the HTS bulk magnets than usual PFM processes.

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