Trapped field and critical current density of MgB_2 bulk fabricated by a capsule method

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We have studied the trapped field B_T and the critical current density J_c of the large MgB_2 bulks fabricated by a capsule method. The maximum B_T values of the bulks with 20 mm, 30 mm, and 38 mm in diameter, respectively, were 1.43 T at 13.5 K, 1.5 T at 16.5 K, and 1.77 T at 15.5 K. The increase in the B_T value with diameter at 20 K was smaller than that expected by the Bean's critical state model. The J_c values were 1.2-1.6$\times 10^5$ A/cm^2 for the 20 mm diameter bulk and 0.7-1.3$\times 10^5$ A/cm^2 for the 30 mm diameter bulk at 20 K in the self field, which can explain the suppression in the B_T for the larger bulks.

INTRODUCTION

Since the discovery of superconductivity in MgB_2 with the critical temperature T_c=39 K, it has been researched for the practical applications, such as wires and thin films. Several groups reported that MgB_2 bulk trapped the tesla-order magnetic field [1, 2]. The B_T value of about 2.3 T at 6 K was obtained for the MgB_2 bulk with 28 mm in diameter and 11 mm in thickness which was sintered under high pressure of 2 GPa [1]. And also, Yamamoto et al. reported the 1.2 T MgB_2 magnet at 17 K with 20 mm in diameter and 5 mm in thickness [2]. Such a tesla-class superconducting bulk magnet has been mainly studied using a single grain of RE-Ba-Cu-O (RE: rare earth elements) bulk by field cooling [3]. However the RE-Ba-Cu-O bulk needs the crystalline orientation, because the intergranular weak links become lower the J_c. On the other hand, for the MgB_2 bulk, we can ignore the problem of intergranular weak links even in polycrystalline samples because of their long coherence length [4]. Therefore, the stronger MgB_2 bulk magnet can be produced by the enlargement of the bulk diameter.

In this paper, we report the trapped field, B_T, and the critical current density, J_c, of large MgB_2 bulks with 20-38 mm in diameter fabricated by the capsule method.

EXPERIMENTAL

MgB_2 bulks were prepared by the capsule method [5]. Figure 1 shows the schematic image of the capsule. Raw powder of Mg (99% in purity, ≦180 μm in grain size) and B (99% in purity, 300 mesh in grain size) were weighted with 1.1:2.0 in molar ratio and ground. The mixture was pressed into pellets under an uniaxial pressure. The precursor pellet was set in the hole of the stainless steel flange, covered by the stainless steel plates, and finally closed by the other flange with the copper gasket using the bolts and nuts. The stainless steel plates were inserted to prevent the reaction of Mg with Cu and the expansion of the pellet during the sintering. The precursor pellet was prepared in air and the capsule was sealed in Ar-atomosphere using a glove box. The closed capsule was sintered at 800 ℃ for 6 h in a box furnace and cooled down to room temperature by furnace cooling. The MgB_2 bulks with 20 mm diameter bulk, 30 mm diameter bulk, and 38 mm diameter bulk, respectively, were named M-20, M-30, and M-38. Sample specifications are listed in Table 1.

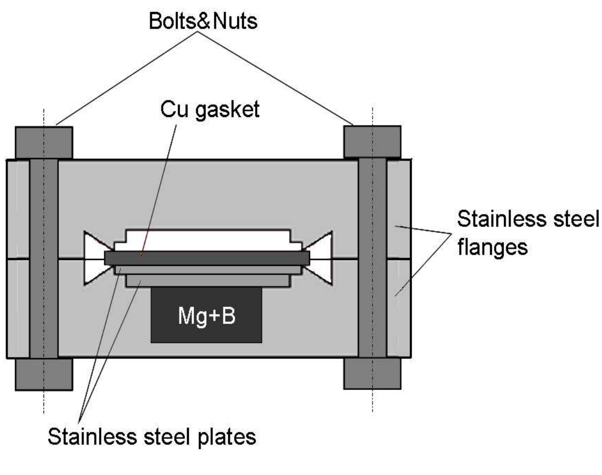

Figure 1 Schematic illustration of the closed capsule

Table 1 Specification of the MgB_2 bulks.

Sample name	Diameter	Thickness	Sintering temp. (℃)	Sintering time (h)	T_c (K)	ΔT_c (K)	Max of B_T
M-20	20.2	5	800	6	38.1-38.4	1.1-1.3	1.43 T at 13.5 K
M-30	30.4	9	800	6	38.3-38.4	1.2-1.3	1.5 T at 16.5 K
M-38	38.4	9	800	6	———	———	1.77 T at 15.5 K

The MgB_2 bulk was magnetized by field cooling (FC) in a magnetic field of 5 T, and then the applied field was decreased to 0 T at a rate of -0.22 T/min. Trapped field was measured by a cryogenic Hall sensor mounted on center of the bulk surface, and the temperature of the bulk was measured by a Cernox thermometer which was also mounted on the bulk surface. We evaluated T_c and J_c by measuring the magnetization using several small pieces cut from the bulk after the FC magnetization measuments. The magnetization was measured using a commercial SQUID magnetometer. J_c was estimated from the hysteresis loop using the extended Bean model.

RESULTS

Figure 2 shows the temperature dependence of the trapped field, $B_T(T)$, of the MgB_2 bulks. The maximum of the $B_T(T)$ values of M-20, M-30, and M-38 bulks, respectively, are 1.43 T at 13.5 K, 1.5 T at 16.5 K, and 1.77 T at 15.5 K. Inset of Fig. 2 shows the diameter dependence of B_T at 20 K, which are estimated by interpolating $B_T(T)$ curve, for the MgB_2 bulks. The B_T (20 K) value increases with the increase of diameter, however the increase in B_T (20 K) is smaller than that expected by the Bean's model [6].

Figure 3 shows the powder X-ray diffraction patterns of the M-20 and the M-30 bulks. The observed peaks of both bulks represent mainly the MgB_2 phase, but a small amount of impurities such as Mg, MgO and $MgCu_2$ phases were observed. The $MgCu_2$ results from the reaction of liquid Mg and Cu gasket. Since the distance between the precursor pellet and Cu gasket for the 30 mm diameter bulk is closer than that for the 20 mm diameter bulk, the $MgCu_2$ phase was detected only in the M-30. We consider that the amount of the $MgCu_2$ phase contained at edge in M-30 is larger than that at center in M-30.

Figure 4 shows the temperature dependence of the normalized magnetization, $M(T)$, in a magnetic field of 4 G after the zero-field cooling. Six pieces were cut from each MgB_2 bulk, whose positions are schematically shown in the figure. The critical temperature, T_c, defined at the midpoint of the transition are 38.1-38.4 K for the M-20 bulk and 38.3-38.4 K for the M-30 bulk. The widths of the transition, ΔT_c, are 1.1-1.3 K for the M-20 bulk and 1.2-1.3 K for the M-30 bulk. The impurity phases seem to deteriorate slightly the T_c.

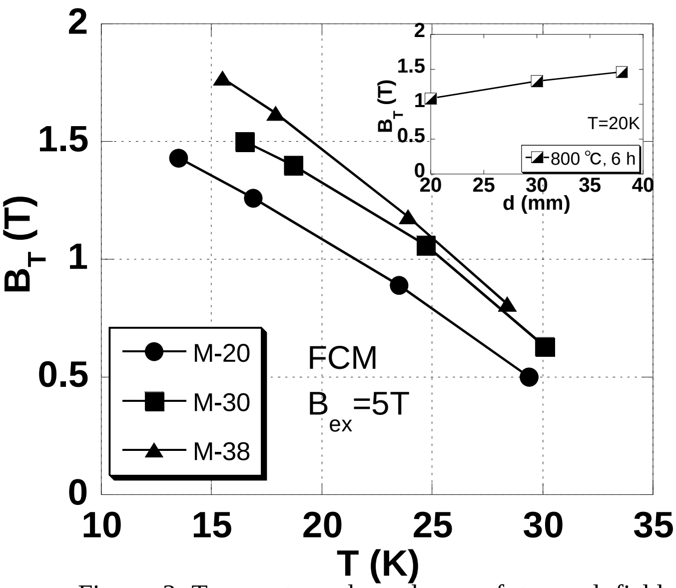

Figure 2 Temperature dependence of trapped field $B_T(T)$. Inset shows the diameter dependence of the trapped field B_T at 20 K.

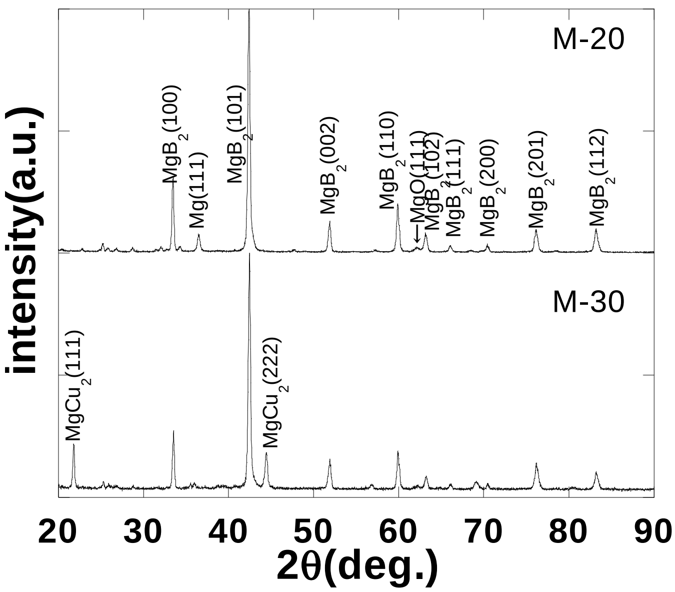

Figure 3 Powder X-ray diffraction patterns

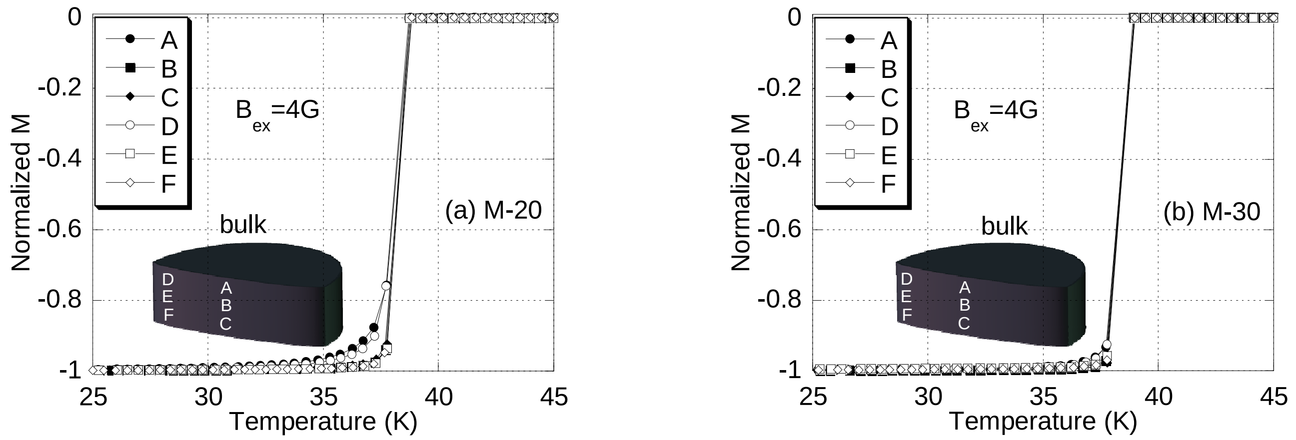

Figure 4 Temperature dependence of normalized magnetization for the M-20 (a) and M-30 (b) bulks. The positions of the samples(A to F) cut from the bulk were shown in the inset.

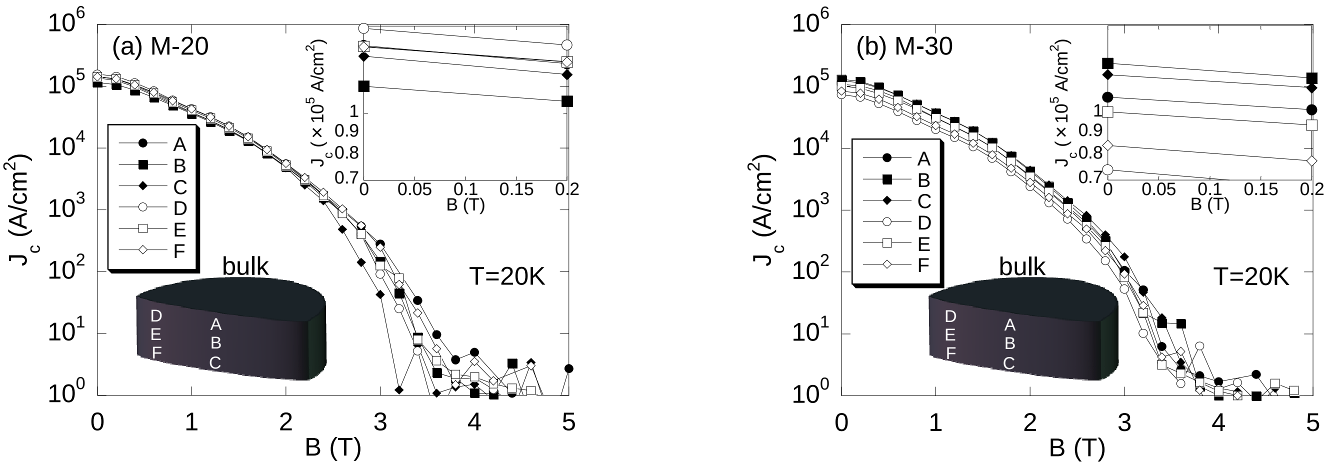

Figure 5 Magnetic field dependence of the critical current density at 20 K for the M-20 (a) and M-30 (b) bulks. Inset shows the extended figure of J_c-B from 0T to 0.2T. The positions of the samples(A to F) cut from the bulk were shown in the inset.

Figure 5 shows the magnetic field dependence of the J_c at 20 K. The measured samples are the same as those for the $M(T)$ measurements. The J_c values are 1.2-1.6$\times10^5$ A/cm^2 for the M-20 bulk and 0.7-1.3 $\times10^5$ A/cm^2 for the M-30 bulk. The J_c values of the M-30 bulk is lower than that of the M-20 bulk. This might mean that the $MgCu_2$ phase does not act as pinning center and decreases the stoichiometric MgB_2 phase in the M-30 bulk. This result is consistent with the suppression in the B_T value of the bulk with 30 mm in diameter.

CONCLUSION

We measured the trapped magnetic field and the critical current density of the MgB_2 bulks with 20-38 mm in diameter and 5-9 mm in thickness fabricated by the capsule method. The important results are described below.
(1) The maximum $B_T(T)$ values of MgB_2 bulks with 20, 30, and 38 mm in diameter, respectively, were 1.43 T at 13.5 K, 1.5 T at 16.5 K, and 1.77 T at 15.5 K.
(2) The $B_T(T)$ values of MgB_2 bulks come to 1.2-1.35 times when their diameter comes to 1.5-1.9 times, which is contrary to the Bean's model.
(3) The J_c values are 1.2-1.6$\times10^5$ A/cm^2 for the 20 mm diameter bulk and 0.7-1.3$\times10^5$ A/cm^2 for the 30 mm diameter bulk at 20 K in the self field, which can explain the suppression in the B_T of the larger bulks. From the results of the powder X-ray diffraction patterns, the existence of $MgCu_2$ phase only in a 30 mm diameter bulk is confirmed.

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REFERENCES

1. Viznichenko R V, Kordyuk A A, Fuchs G, Nenkov K, Muller K H, Prikhna T A and Gawalek W 2003 Appl. Phys. Lett. 83 4360−4362
2. Yamamoto A, Yumoto H, Shimoyama J, Kishio K, Ishihara A and Tomita M 2010 Abstract of 23rd Int. Symp. on Supercond. p 219
3. Tomita M and Murakami M 2003 Nature 421 517−520
4. Kambara M, Babu N H, Sadki E S, Cooper J R, Minami H, Cardwell D A, Campbell A M and Inoue I H 2001 Supercond. Sci. Technol. 14 L5−L7
5. Naito T, Sasaki T and Fujishiro H to be pulished in IEEE Trans. Appl. Supercond.
6. Bean C P 1962 Phys. Rev. Lett. 8 250−253