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Superconducting properties of MgB_2 bulks processed in high magnetic fields

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Abstract

MgB_2 bulk samples were synthesized by the solid-reaction process in high magnetic fields. The effect of magnetic fields on the microstructure and superconducting properties of MgB_2 tapes has been investigated by using X-ray diffraction, scanning electron microscope and magnetic measurements. Under the application of an 8 T magnetic field, the critical transition temperature, T_c, remained unchanged, and the critical current density, J_c was enhanced by a factor of more than 2 for both temperatures of ~5 K and 20 K. The experimental results suggested that the high magnetic field is effective for improving J_c of MgB_2 superconductors.
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Keywords: MgB_2; Critical current density J_c; Magnetic-field annealing

1. Introduction

MgB_2 is a material whose superconducting properties were discovered in 2001 [1]. It will be a potential material for large-scale engineering applications and electronic devices because of its simple crystal structures, large coherence lengths, high critical current densities and transparency of grain boundaries to current [2]. However, the critical current density J_c of MgB_2 drops rapidly in magnetic field, therefore, research approaches have been directed towards either improving J_c by improving grain connectivity, or improving in-field performance by different methods.

In 1987, Farrel et al. [3] has first reported that the alignment of the YBCO particles could be induced by the magnetic field, when YBCO powders, which were mixed with the epoxy solution, dried in a 9.4 T magnetic field. Soon after, a high magnetic field was introduced in the solidification processing by Rango et al. [4]. The experimental results indicated that annealing YBCO in a magnetic field not only introduces crystallographic orientation but also improves the quality of the intergranular contacts. Since then, a lot of experiments about the processing of high T_c superconductors (HTS) under high magnetic fields have been eagerly carried out. It has been found that the degree of grain alignment and critical current density in HTS were much enhanced by an external magnetic field during the fabrication process, due to the anisotropy of magnetic susceptibility [5–7]. It is known that the structure of MgB_2 is anisotropic. If a magnetic field is applied during the MgB_2 heating process, J_c improvement and other field effects are expected. Actually, more recently, Aksan et al., [8] mixed high purity MgB_2 powder with an organic binder and dried in a magnetic field of 1 T for 75 h. Then samples were heat-treated at 950 °C for several hours under an argon atmosphere. They found that the critical temperature T_c and the critical current densities were both increased by drying under magnetic fields.

In this paper, we report the experimental results of MgB_2 bulk samples heat-treated under high magnetic fields by solid-state reaction method.

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2. Experimental

High purity Mg (99.8%) and B (99.99%) powders were mixed thoroughly by grinding in the air for 1 h. Extra Mg powder was added in the precursor in order to compensate for the loss of Mg at high temperature. The ground powders were unidirectionally pressed into pellet of 14 mm diameter under ~30 Mpa pressure. The pellets were packed in Zr foil, then heat-treated at 800 °C in vacuum for 1 h. During the heat-treatment process, a constant magnetic field H_a of 8 T was applied perpendicular to the surface of pellets. For comparison, the samples were prepared under the same conditions without the magnetic field.

The phases of all the samples was studied by X-ray diffraction (XRD). The microstructure was examined by scanning electron microscope (SEM). The magnetization property was measured using a superconducting quantum interference device (SQUID). The magnetic measurement were carried out and the critical current density J_c was calculated using bean model from ΔM on the magnetization loop.

3. Results and discussion

Fig. 1 shows XRD patterns of the surface of MgB_2 bulk samples heat-treated at magnetic fields of 0 and 8 T. It is clear that both samples compose of almost a single phase of MgB_2 containing a small amount of MgO. We also performed the XRD measurements along the bulk plane perpendicular and parallel to the direction of magnetic fields for the 8 T samples. However, no appreciable difference in texture development was observed between them.

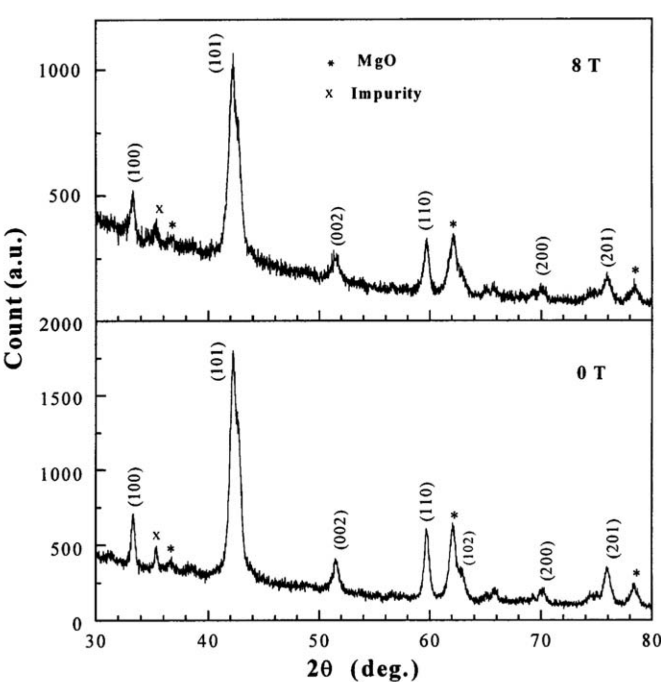

Fig. 1. X-ray diffraction patterns of the surface of MgB_2 bulks heat-treated in magnetic fields of 0 and 8 T.

The superconducting transition curves of the 0 and 8 T samples determined by susceptibility are shown in Fig. 2. Both samples show a sharp transition of magnetization versus temperature. The onset transition temperature is 37.1 K for the 0 T samples while 37 K for the 8 T bulks, indicating that the magnetic field has almost no influence on T_c.

The J_c values as a function of magnetic fields at different temperatures for the 0 and 8 T samples are shown in Fig. 3. Clearly, the larger J_c values were achieved in the 8 T sample at all temperatures and in the entire field region. At temperatures of 5 and 20 K, the J_c of 8 T samples was more than two times larger than that of the bulks processed in the absence of magnetic field. Magnetic field dependence of J_c did not change with the application of Ha, meaning that the flux pinning below 5 T is not improved by the applied magnetic field. However, at 30 K, the J_c difference

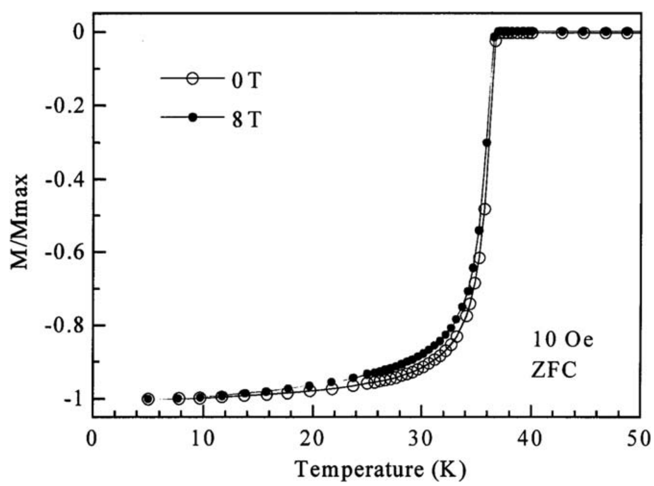

Fig. 2. Normalized magnetic susceptibility versus temperature for the 0 and 8 T bulks.

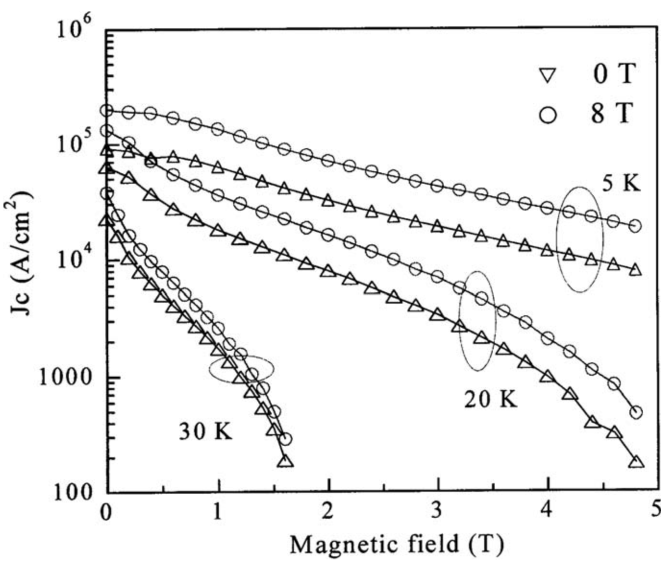

Fig. 3. Magnetic field dependence of J_c for the 0 and 8 T bulks at various temperatures, as measured by magnetization.

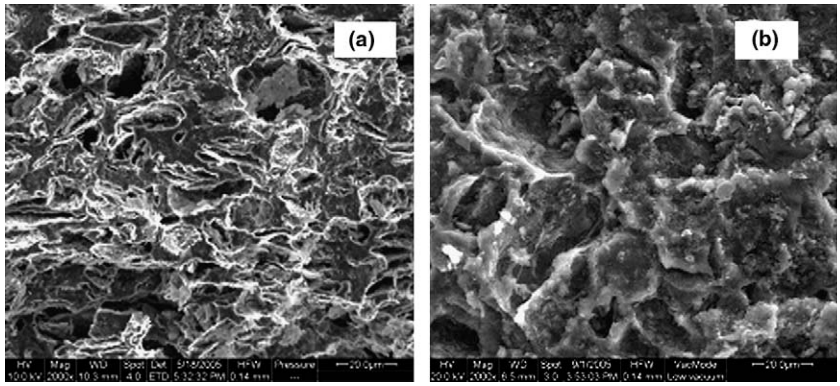

Fig. 4. SEM micrographs of bulk samples which were heat-treated in a (a) 0 T and (b) 8 T magnetic field.

between the two samples became small with increasing of the magnetic field. The low J_c values of 0 T sample can be partly explained by the porous microstructure.

In order to investigate the reason for the J_c improvement, we studied the differences in the microstructures of the bulks with and without magnetic field. Fig. 4 shows the SEM images of fractured surface of the 0 and 8 T samples. It is clearly seen that the 0 T samples is quite porous and loose. Large voids and poor intergrain connections were presented. In contrast, with the application of strong magnetic field, densification of the MgB_2 core obviously occurred, resulting in the quite uniform microstructure and the better connectivity between the MgB_2 grains. These results are in good agreement with recent reports, in which the J_c enhancement of MgB_2 was achieved by the improvement in the grain coupling as a consequence of densification of the tape core [9,10]. The present results demonstrated that the 8 T magnetic field can improve the connectivity of MgB_2 grains and hence the increased J_c values. The effects of magnetic field on processing of in situ MgB_2/Fe tapes will be published elsewhere [11].

4. Conclusion

MgB_2 bulk samples were prepared by solid-state reaction under the 8 T magnetic field. The field samples showed an enhanced critical current density in comparison to the 0 T ones. The reason can be attribute to the denser microstructure and the improved connectivity of MgB_2 grains.

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References

[1] J. Nagamatsu, N. Nakagawa, T. Muranaka, Y. Akimiatu, Nature 410 (2001) 63.
[2] C. Buzea, T. Yamashita, Supercond. Sci. Technol. 14 (2001) R115.
[3] D.E. Farrel, B.S. Chandrasekhar, M.R. Deguire, M.N. Fang, V.G. Kogan, J.R. Clem, K. Finnemore, Phys. Rev. B 36 (1987) 4025.
[4] P. de Rango, M. Lees, P. Lejay, A. Sulpice, R. Tournier, M. Ingold, P. Germi, M. Pernet, Nature 349 (1991) 770.
[5] H. Maeda, P.V.P.S.S. Sastry, U.P. Trociewitz, J. Schwartz, K. Ohya, M. Sato, IEEE Trans. Appl. Supercond. 13 (2003) 3339.
[6] S. Awaji, Yanwei Ma, W.P. Chen, H. Maeda, K. Watanabe, M. Motokawa, Curr. Appl. Phys. 3 (2003) 391.
[7] Yanwei Ma, K. Watanabe, S. Awaji, M. Motokawa, Appl. Phys. Lett. 77 (2000) 3633.
[8] M.A. Aksan, M.E. Yakinci, Y. Balci, Physica C 408–410 (2004) 132.
[9] Yanwei Ma, H. Kumakura, A. Matsumoto, K. Togano, Appl. Phys. Lett. 83 (2003) 1181.
[10] A. Serquis, L. Civale, D.L. Hammon, X.Z. Liao, J.Y. Coulter, Y.T. Zhu, M. Jaime, D.E. Peterson, F.M. Mueller, V.F. Nesterenko, Y. Gu, Appl. Phys. Lett. 82 (2002) 2847.
[11] Yanwei Ma, Aixia Xu, Xiaohang Li, Xianping Zhang, S. Awaji, K. Watanabe, Jpn. J. Appl. Phys. 45 (2006) L493.