論　文　要　旨
Thesis Abstract

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主論文題名　（Title）

Innovative Techniques for Enhancement of Superconducting Characteristics of Bulk MgB_2

内容の要旨　（Abstract）

The objective of this thesis was to study the ways, how to improve critical current density (J_c) in polycrystalline magnesium diboride (MgB_2) bulk. The superconducting devices demand economical operation, a cheap manufacturing route, and a light weight. In view of these requirements, MgB_2 meets most of the criteria making it a promising candidate. Properties such as decent critical transition temperature (T_c), cheap and abundant raw materials, and light weight elements are appealing qualities for practical applications. It is also well known that MgB_2 thin films have high J_c (~ 10^7 to 10^8 A/cm^2) and upper critical field (H_{c2}~ 60T at 0K). However, these values have been never seen in polycrystalline MgB_2 bulks; in fact, the J_c values are almost two orders of magnitude lower than those observed in thin films. The main reason is poor flux pinning, resulting in low H_{irr}, H_{c2} & J_c. Poor connectivity between grains and low density are the issue. Sintering has been a standard technique (700 to 850 °C), resulting in good crystallinity and large grain size. Lack of flux pinning at grain boundaries and crystal defects led to considerable reduction of self-field J_c.

To tackle these issues, we tried to manipulate microstructure with various precursors. In this thesis, we fabricated MgB_2 bulk using solid state sintering at 775 °C for 3 hours. Since, the melting point of boron is very high (~2000 °C) compared to reaction temperature, boron precursor particle size plays a vital role in optimizing J_c. We used a commercial nano-amorphous boron and the results were astonishing. J_c of 408 kA/cm^2 was observed at 20 K, self-field. SEM micrographs revealed the nano-sized grains in the final microstructure, which approved our hypothesis and was successful in improving self-field J_c. In order to improve the high field J_c and upper critical field H_{c2}, we resorted to carbon doping. One serious issue with the carbon doping was lack of homogeneous distribution of carbon in the matrix. To overcome this issue, we prepared carbon-encapsulated boron (CEB) made from pyrolysis of Diborane, hydrogen and gaseous hydrocarbon. It was found that low wt% of carbon coating leads to the best results.

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内容の要旨(Abstract)

A high-field J_c and H_{c2} were observed in 1.5 wt% carbon encapsulated boron based MgB_2 bulk. Tremendous J_c of 660 and 250 kA/cm^2 were observed at 0 and 2 T; 10 K. H_{c2} (obtained by extrapolation) was also substantially improved, being almost equivalent to the best records reported in MgB_2 bulk system so far, however at a slight expense of T_c. To further improve this result, our group studied the effect of co-dopants such Ag and CEB. Microstructural analysis exposed Ag-Mg phases formed in the matrix and optimum performance was observed for 4 wt% Ag. To compensate the loss of Mg reacting with Ag, as well as to increase the Ag-Mg phase fraction, we studied the optimization of Mg precursor concentration. 7.5 wt% excess of Mg resulted in the best result, with highest Ag-Mg phase (2 wt%), high irreversibility field (H_{irr}) of 4.76 Tesla and large J_c such as 440 kA/cm^2 at 20 K, self-field. SEM analysis confirmed existence of secondary nanoscopic Ag-Mg phases (20-40 nm), acting as pinning centers.

The special clean boron precursors first used were expensive, which might make the final product costly. In order to make the processing cheap while maintaining high performance, we explored a novel technique of *high-energy ultra-sonication* using various media such as ethanol, hexane, and distilled water. We successfully produced nano-sized boron via ultra-sonication, and arrived at high J_c in the final bulk. Beside size refinement, the obtained fine boron powder was free of B_2O_3, due to which the MgB_2 bulks were of high quality. SEM analysis clearly revealed that short duration of ultra-sonication results in particle refinement, while prolonged ultra-sonication causes agglomeration of boron particles. MgB_2 bulks fabricated from various systems were studied and the best results were observed in MgB_2 prepared with for 15 min ultra-sonicated boron dispersed in ethanol and for 30 min ultra-sonicated boron dispersed in distilled water. Self-field J_c of approximately 300 kA/cm^2 at 20 K was achieved (almost 35% improvement compared to a regular bulk MgB_2).

Author has employed unique precursors such as nano-amorphous boron, carbon encapsulated boron, excess Mg with Ag addition and boron precursor refined via cheap novel ultra-sonication. The ultra-sonication technique is scalable and cost-effective. Its use resulted in 35% J_c improvement. The results were published in renowned *international Journals.* This improvement in bulk MgB_2 superconducting system makes it commercially viable for industrial sector, for a mass production of rare-earth-free bulk superconducting materials for super-magnet applications.

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