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論　　文　　要　　旨
Thesis Abstract

2022 年 08 月 18 日

※報告番号	第　　　　号	氏　名 (Name)	XING Yiteng

主論文題名　（Title）

Densification of MgB_2 superconducting cryomagnets: Synthesis and physical properties studies

内容の要旨　（Abstract）

While most applications of superconductors are based nowadays on conventional low temperature superconductors (LTS) such as NbTi, Nb_3Sn and some high temperature superconductors (HTS) like REBCO, the possibility to use liquid hydrogen as a fuel for airplanes and other applications on the one hand and the availability of powerful cryo-coolers on the other hand make light MgB_2 superconductors very attractive for large scale applications. However, the main issues of un-doped MgB_2 bulks fabricated by conventional sintering are their poor density and the lack of pinning centers. If MgB_2 bulks present a low relative density as compared to the theoretical value, the resulting poor grain connectivity leads to a decrease of the critical current density, J_c at low magnetic field. Otherwise, the lack of pinning centers in the superconducting materials results in the drop of J_c at high field.

To resolve these issues, highly dense bulk MgB_2 samples have been elaborated by the unconventional "Spark Plasma Sintering" (SPS) technique according to different processing routes. SPS is a rapid consolidation method that results in a better control of the sintering kinetics than the other techniques. The heat source is not external but is an electric current (AC, DC or pulsed) that flows across the die containing the powder to sinter. Simultaneously, a uni-axial pressure is applied. The main difference between SPS and other sintering methods is that SPS allows to prepare dense samples while controlling the grain growth and to save processing time. In our study, different precursors were used to understand the sintering mechanisms and to optimize the superconducting properties : i) commercial MgB_2 powders ii) mixtures of magnesium and nano boron powder (Mg + 2B) iii) mixtures of Mg and MgB_4 powder and iv) mixtures of magnesium and carbon-encapsulated boron powder (Mg+2B/C) for an "in-situ" reactive synthesis. The density of the obtained MgB_2 bulks was up to 99 % of the theoretical density of the material, which is the highest so far reported in literature. Then structural and microstructural characterizations were carried out with these samples and correlated to their superconducting properties, in particular their critical current densities, J_c measured at 20

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K. The optimized thermomechanical conditions for the in-situ MgB_2 bulks were found to be T< 800°C and P = 300 MPa using a special tungsten carbide (WC) mold. A high J_c = 675 kA/cm^2 was obtained in self-field and remarkably for an un-doped bulk MgB_2, J_c was above 10 kA/cm^2 at 4 T. Compared to the bulks sintered in conventional graphite molds, the bulks sintered using WC molds show a significant improvement of their critical current density at both low and high fields. This can be attributed to the strong densification of the nano grains and the suppression of the Mg-depleted phases (MgB_4), suggesting that it is possible to enhance the grain connectivity by increasing the pressure and decreasing the temperature applied during Spark Plasma Sintering.

To further improve the superconducting properties of MgB_2 bulks, the effect of chemical doping has been investigated. We noticed that a moderate Mg addition in the samples sintered at high temperatures (>900°C) can reduce the evaporation of magnesium and improve the intergrain connectivity and consequently, the critical current density J_c at low fields. Substitution of boron by carbon depresses slightly the critical temperature, T_c but enhances vortex pinning, with the result of optimizing performances at high field (J_c ~ 10 kA/cm^2 at 5 T and 20 K) using the mixtures containing carbon-coated boron or nano SiC doping.

In addition, the functional properties have been also investigated for large bulks with diameter D_{sc} fabricated with the commercial MgB_2 powder, especially the levitation forces, F_Z and the stability in superconducting magnetic levitation (SML) as well as the field trapped by the samples. The force measurements have shown that there is a linear relation between F_Z and D_{sc}^3. Otherwise, the levitation forces do not depend on the thickness h of the samples above some threshold and are slow varying functions of h below the threshold. This behavior can be linked to the limited thickness t of the layer carrying the superconducting currents. We have also investigated the effect of the working temperature. The results seems to show that stability can be improved by increasing the temperature, but that this causes a decrease of the levitation force as a consequence of the reduction of the critical current density J_c. These measurements have revealed that large diameter MgB_2 discs can be good candidates for SML systems using a cryogenic fluid such as hydrogen or neon. Concerning field trapping, the best field trapped with a 20 mm diameter and 10 mm thick sample at 20 K was around 2.16 T. However, it is difficult to trap high fields with large MgB_2 discs because of the occurrence of flux jumps.

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