Development of high performance MgB2 superconducting wires

葉，術軍

https://doi.org/10.15017/1441201

出版情報：九州大学，2013，博士（工学），課程博士
バージョン：

（別紙様式２）

論　文　要　旨

区　分	[✓ 甲]・乙	氏　名	葉　術軍

論文題名

Development of high performance MgB_2 superconducting wires
（高性能MgB_2超伝導線材に関する研究）

Abstract

MgB_2 is expected to be used in no-helium conditions to replace metallic superconductors that are operating in a liquid helium environment. Low cost is the most important advantage of MgB_2 to be used as a practical superconducting wire. Currently, there have already been products using MgB_2 superconductor, but the cost per unit length and unit superconducting current density of these products are not so low because the critical current properties of these MgB_2 wires are not high enough to operate in the expected condition. The expected condition for MgB_2 wire operation is at ~20 K using a cryocooler or liquid hydrogen. The main work of this thesis is to enhance the critical current properties for MgB_2 wires at 20 K and 5 T.

Internal-Mg-diffusion (IMD) process produces higher density MgB_2 layer than that of Powder-in-tube (PIT) process, thus IMD MgB_2 wires have higher critical current properties. However, un-reacted B particles were observed in the MgB_2 layer of IMD-processed wires fabricated with low quality B powder (325-mesh, 99%). In chapter 2, I found that some Mg powder addition is effective to decrease the un-reacted B particles and enhance the critical current density (J_c) values. On the other hand, Mg powder addition also formed voids in MgB_2 layer and these voids decreased the J_c values. If the amount of Mg powder in the B layer is increased, the Mg rod diameter should be decreased simultaneously in order to maintain a Mg:B ratio of 1:2, corresponding to stoichiometric MgB_2. Consequently I developed a new hybrid method for fabricating MgB_2 wires by a combination of IMD and PIT processes. The MgB_2 layer thickness is larger and the diameter of the central hole is smaller than those of a conventional IMD processed wire, thus MgB_2 area fraction is higher. The proposed method also achieves a much higher MgB_2 layer density, and thus a much higher J_c, than those obtained by the PIT method. The combination of these factors leads to the enhanced engineering critical current density (J_e) value. The new method introduced in chapter 2 is developed for the low quality B powder, but it is also effective for nano-sized B high quality powders used in chapter 5 and in chapter 6 because it could be effectively used to decrease the B-rich region caused by these nano-sized powders.

The multi-filamentary superconducting wires are important for practical applications. In chapter 3, we succeeded in fabricating IMD-processed 37-filamentary MgB_2 wires. SiC-added 37-filamentary MgB_2 wires show the highest J_c value (7.6×10^4 A/cm^2 at 4.2 K and 10 T) among all of the IMD-processed MgB_2 wires fabricated under the same conditions (mono-filamentary and 7-filamentary). The short Mg diffusion distance of 37-filamentary IMD-processed MgB_2 wires decreases un-reacted B particles. This is the main factor to raise the J_c values. The successful fabrication of 37-filamentay wires indicates that the IMD process can be used to fabricate MgB_2 wires for large-scale applications.

It was reported that the co-addition of SiC and ethyltoluene is effective in the PIT-processed MgB_2 wires. Accordingly, it may be also effective in the IMD-processed MgB_2 wires. In chapter 4, I have carried out the

SiC and ethyltoluene, toluene, or dimethylbenzene co-addition to IMD-processed MgB_2 wires. The J_c properties are enhanced by the toluene and dimethylbenzene, but not so good for ethyltoluene.

The researchers in Ohio State University and Hyper Tech Company used a special plasma-synthesized 2% carbon-coated B powder (Special Materials Inc., SMI powder) to fabricate thin IMD-processed MgB_2 wires (diameter: 0.55 mm). They obtained high J_c and J_e for different samples. The small diameter of the wire is considered to decrease the Mg diffusion distance, which leads to an improved reaction between Mg and B, thus a high J_c is obtained. I also tried this B powder, however, I could not obtain good results as theirs. After investigating the B powder, I found that many BCl_3 (source material for this B powder) exists in the B powder. Since dimethylbenzene dissolve BCl_3, and our experiments in chapter 2 also showed dimethylbenzene enhanced the J_c of IMD-processed MgB_2 wires, I used the dimethylbenzene to remove BCl_3 from the B powder. The dimethylbenzene decreased the BCl_3 in B powder and then I obtained J_c values higher than Ohio state university in chapter 5. For both Ta- and Fe-sheathed wires, the highest J_c value was about 1.2×10^5 A/cm^2 at 4.2 K and 10 T, and the J_e value was about 1×10^4 A/cm^2. Furthermore, the Fe-sheathed wire exhibited a J_c of 7.6×10^4 A/cm^2 and a J_e of 5.3×10^3 A/cm^2 at 20 K and 5 T, which are the highest values reported for MgB_2 wires to date.

The carbon-coated nano-sized B powder is responsible to obtain the high J_c and J_e for IMD-processed MgB_2 wires. However, the C-coating process using plasma method is not easy, thus it is expensive. Furthermore, this B powder is unstable because BCl_3 exists. Therefore, I tried a new B powder added with an aromatic hydrocarbon (coronene, $C_{24}H_{12}$) as a carbon source, which is described in chapter 6. The similar level of high J_c and J_e values to the carbon-coated B powders in chapter 5 were obtained. The J_c properties are expected to be further enhanced by optimizing the coronene-coating and heat treatment conditions. It is easy to obtain this coronene-coated B powder and the powder is stable. And the amount of carbon addition is also easily controlled. Using the new B powder with $C_{24}H_{12}$ coating we can expect to fabricate high performance MgB_2 wires for large-scale practical applications with low cost.