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Enhanced critical current density of MgB_2 superconductor using a milled MgB_4 precursor

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ABSTRACT

The synthesis of bulk MgB_2 superconductors from Mg and MgB_4 precursors instead of the conventional in situ process increases the packing density, but further enhancement of the critical current density is required. Herein, to improve the critical current density of bulk MgB_2, the MgB_4 precursor was subjected to planetary milling in toluene. The MgB_4 powder was then mixed with Mg and heat-treated at 650 °C for 1 h to synthesize bulk MgB_2. The microstructure, phases, and superconductivity of bulk MgB_2 were investigated to determine the effect of MgB_4 milling. MgB_4 milling decreased the MgB_2 grain size, and carbon incorporation from the milling solvent was observed, which caused the deterioration of the MgB_2 crystallinity. These changes caused a reduction of the critical temperature; however, the critical current density was improved due to the increased magnetic flux pinning sites such as grain boundary and lattice distortion.

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1. Introduction

Although superconductors have limited specialized applications, they play important roles in the medical and research fields. For instance, superconductors are core materials in particle accelerators and analytical equipment such as nuclear magnetic resonance spectrometers. In the medical field, superconductors are used in magnetic resonance imaging, the demand for which is increasing with the ageing of the global population and market expansion in developing countries.

In the above applications, the most commonly used superconductors are NbTi and Nb_3Sn, which have extremely low superconducting critical temperatures (T_c) of 9 and 18 K, respectively [1,2]. In addition, these superconductors have low upper critical fields (H_{c2}) of 10 and 20 T at 4.2 K, respectively [1,2], which limit equipment performance. Therefore, there have been various attempts to use high-temperature superconductors, such as ReBCO Re = Y, Sm, Gd, etc.). The T_c values of high-temperature superconductors are greater than 77 K and the H_{c2} at 4.2 K are greater than 100 T, which is superior to the performance of low-temperature superconductors [3]. However, these high-temperature superconductors exhibit anisotropy and are brittle, which hinders the production and processing of wire-shaped products. In addition, the high-temperature superconductors require high process costs.

MgB_2 superconductors have a relatively high T_c of 39 K, low current anisotropy, and a long coherence length [4]. Furthermore, MgB_2 is an intermetallic compound that can be manufactured in wire form by the powder-in-tube (PIT) method. For these reasons, MgB_2 has attracted much attention as a substitute for low-temperature superconductors. Various studies have been conducted to improve the performance of MgB_2 wires by increasing the critical current density (J_c). The most common method of enhancing J_c is to provide magnetic flux pinning sites, such as grain boundaries or defects. The grain boundary density can be increased by either reducing the heat treatment temperature [5–8] or refining the raw material through a milling process [9,10]. Moreover, defects can be introduced by the addition of carbon [11–16] or SiC [17,18] to the MgB_2 lattice.

Conventionally, MgB_2 is produced by an in situ process involving the direct reaction of Mg and B. As an alternative, the production of MgB_2 from MgB_4 and Mg precursors (MgB_4 process) has been attempted with the aim of improving the superconductivity by increasing the MgB_2 packing density [19–24]. With the in situ process, many pores are formed by the diffusion or melting of Mg during heat treatment [25]. It has been reported that such structural defects in MgB_2 significantly reduce the current density [26,27]. As the MgB_4

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