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Carbon nanohorn doping in MgB_2 wire prepared by suspension spinning

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Abstract

Carbon nanohorn (CNH) doping in MgB_2 wire prepared by suspension spinning was studied to enhance flux pinning. The mixed powders of MgB_2 and CNH with nominal composition of $(MgB_2)_{0.95}C_{0.05}$ were suspended in a mixed poly(vinyl alcohol) solution. The as-drawn filaments were hot-pressed under 20 MPa at 200 °C for 8 h. The samples were enveloped by an iron sheet with a pellet of mixed powder of Mg and B and vacuum-sealed in a fused quartz tube, and then sintered at the temperature ranging from 885 °C to 900 °C for 2–3 h. The superconductivity of the samples was studied by electrical resistivity and SQUID method. Serious deterioration of T_c was not observed for the doped sample. The CNH doping resulted in enhancement of the transport J_c values at 4.2 K in high fields ranging from 6 T to 10 T by sintering at 885 °C for 2 h. The superconductivity at 4.2 K was maintained by applying the field of 14 T for the doped sample sintered at 900 °C for 3 h.

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1. Introduction

A number of processing techniques to fabricate MgB_2 wires or tapes have been developed to realize high J_c for practical applications of MgB_2 such as magnets and cables. Among these techniques,

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the powder-in-tube (PIT) process is popular to fabricate the MgB_2 wires or tapes [1,2]. However, the PIT technique requires expensive fabrication costs and many steps to form good quality wires. In addition, it is a serious point to find a suitable sheath material to prevent from the degradation of the superconductivity. We have developed simple and low-cost fabrication process for filamentary MgB_2 superconductors by a suspension spinning method [3,4]. This technique is attractive from the viewpoint of practical applications because the large-scale wire fabrication leads to reduction of costs and time.

There have been many studies of the enhancement of J_c value for MgB_2 superconductors. One is the improvement of poor connectivity and the other is the introduction of pinning centers. Therefore, several investigations for the effects of chemical substitutions or additions on J_c value of MgB_2 superconductors have been reported [5–8]. Among various studies, the effect of C doping on superconductivity in a MgB_2 compound has been investigated using amorphous carbon and diamond. Recently, the effect of carbon nanotube (CNT) doping on J_c and flux pinning has been reported, showing enhancement of J_c and flux pinning [7,8]. Further experimental data on a wider range of nano-scale additions and/or substitutions are necessary to improve the J_c value and to understand the pinning properties in MgB_2.

In this paper, we examined the field dependence of J_c for the filamentary MgB_2 doped with nano-scale cone-shaped graphite called single-wall carbon nanohorn (CNH).

2. Experimental

MgB_2 filaments were prepared by a suspension spinning method as reported previous paper [3]. The commercially available MgB_2 powders of 98% purity (Alfa Aesar, Inc.) were mixed with single-wall CNHs prepared by pulsed arc discharge between pure carbon rods in the atmospheric pressure of air [9]. After removal of amorphous carbon, the purity of CNHs aggregated to a globular form with 50 nm in diameter was higher than 90%. The mixed powders with nominal composition of $(MgB_2)_{0.95}C_{0.05}$ were passed through 350 stainless mesh sieves and then suspended in a mixed poly(vinyl alcohol) solution of dimethyl sulfoxide and hexamethyl phosphoric triamide. The suspension with suitable viscosity was extruded as a filament into a precipitating medium of methyl alcohol and coiled on a drum. The as-drawn filaments were cut to 100 mm length and then hot-pressed under 20 MPa at 200 °C for 8 h to remove volatile components and connect the grains. The filamentary samples and a pellet of mixed Mg and B powders were enveloped an iron sheet to prevent Mg loss. The samples were sealed in an evacuated quartz tube and heated at 885–900 °C for 2–3 h.

The electrical resistivity of the filamentary sample was measured by a standard four-probe method. Silver paint was used to connect silver-sputtered parts of the filaments with Ag wires 100 μm in diameter. The sample was embedded in a substrate using epoxy resin and set on a measuring holder. External magnetic fields were applied in a direction normal to the filament length using a helium-free 15 T superconducting magnet at the High Field Laboratory for Superconducting Materials, Tohoku University. Currents were passed along the direction of the filament axis and normal to the applied magnetic field. J_c was defined by the offset method from the point on the I–V curve at which the voltage of 1 μV appeared between voltage terminals separated 2 mm.

The magnetization measurements of the sample were carried out with a SQUID magnetometer (Quantum Design MPMS-5). The magnetic J_c values were calculated on the modified Bean model using the following equation:

$$J_c(H) = 20\Delta M/(b - b^2/3l),$$

where ΔM is the difference of magnetization (emu/cm^3) measured for ascending and descending applied field, and b and l are the sample thickness (cm) and length (cm) of a rectangular cross-section of the sample perpendicular to the applied field.

The microstructure of a sample was also studied using scanning electron microscope (SEM) and X-ray diffractometer (XRD). The longitudinal cross-section of the sample embedded on the substrate was polished for the SEM observation.