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Growth of superconducting MgB_2 fibers for wire applications

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Abstract-- **Superconducting MgB_2 fibers are in-situ grown by a diffusion method. The fibers are prepared by exposing B filaments to Mg vapor inside a folded Ta foil over a wide range of temperature and growth time. The materials are sealed inside a quartz tube by gas welding. The as - grown fibers are characterized by scanning electron microscopy and energy dispersive x - ray analysis. The fibers have a diameter of about 110 μm. Surface morphology of the fibers looks dependent on growth temperature and mixing ratio of Mg and B. Radial distribution of Mg ions into B is observed and analyzed over the cross - sectional area. Transport properties of the MgB_2 fibers are examined by a physical property measurement system. The MgB_2 fibers grown at 900 °C for 2 hours show a superconducting transition at 39.8K with $\Delta T_c <$ 2.0 K. Resistance at room temperature MgB_2 is 3.745 Ω and residual resistivity ratio (RRR) is estimated as 4.723.**

1. INTRODUCTION

The discovery of superconductivity in MgB_2 with $T_C \sim$ 39 K has attracted much interest in science and technology since it shows the highest transition temperature among intermetallic compounds [1]. It has opened a new possibility to synthesize cheaper superconducting fibers with higher performance compared to conventional NbTi and Nb_3Sn materials. Many groups have been trying to draw the MgB_2 fiber with several methods [2]. We report in-situ fabrication of MgB_2 fibers by a diffusion method.

Earlier, Canfield et al. made the MgB_2 fibers by exposing B filaments to Mg Vapor [2]. The critical temperature of MgB_2 fibers was 39.4K. Resistivity at 40K was 0.38μΩcm and residual resistivity ratio (RRR) was 25.3. The fiber showed the upper critical field (H_{c2}) at 0K was similar to 12.5T and J_C was approximately 3×10^5 A/㎠ at 20K. But, amount of Mg was presumably too rich in their MgB_2 fibers. The purpose of this paper is to report fabrication and measurement of the superconducting properties of MgB_2 fibers.

2. EXPERIMENTALS

Superconducting MgB_2 fibers were grown by a diffusion method. B fibers (Specialty Materials Inc. a diameter of 100 μ m with a 15μ m tungsten core) were cut to 20 - 25 mm length from a continuous spool. The fibers were produced by sealing B fiber and Mg into a Ta foil. The foil was sealed inside a quartz tube by gas welding. The tube was placed in a furnace where it was heated under 850 ~ 900℃ and held for approximately two hours.

The as-grown fibers were measured by a physical property measurement system (PPMS, Quantum Design) for electrical transport measurement as functions of temperature and magnetic field. Transport properties were measured by four probe geometry.

3. RESULTS

Upon opening the Ta foil it become clear that there had been a reaction between the B fiber and the Mg vapor. Whereas the B fibers are straight and more flexible before the reaction, the MgB_2 fibers after the reaction are brittle and broken. In Fig. 1, optical microscopic images of the MgB_2 fibers are shown.

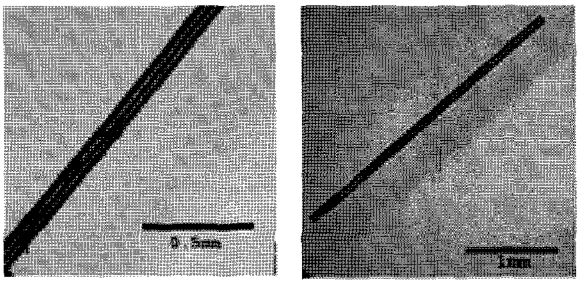

Fig. 1(a), (b) Optical microscopic images of MaB_2 fiber

Fig. 2 shows scanning electron microscope images of the fibers after reaction. Since a volume of tungsten core is too small, a tungsten core in the fiber does not seem to react with the materials interested. The MgB_2 fiber has a diameter of approximately 110 μ m. The increased diameter of the fiber is consistent with observations that there is volume expansion associated with the formation of the MgB_2 powders during synthesis [3]. Although the MgB_2 fibers are somewhat brittle, the integrity of the filament segments is preserved during the exposure to the Mg vapor, i.e. the fibers do not decompose or turn into powder. In the Mg-rich case, the fiber has Mg crystal on the surface as shown in Fig. 2(b).

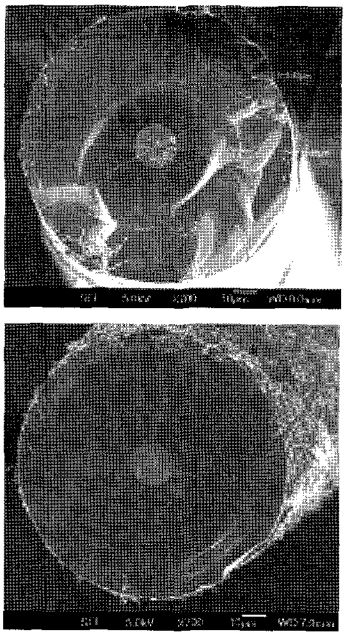

Fig. 2. (a) Scanning electron microscopic image of cross section of MgB_2 fiber and diameter of MgB_2 fiber. (b) Scanning electron microscopic image of cross section of MgB_2 fiber in Mg-rich vapor.

Indeed, controlling of Mg vapor pressure is very important parameter to make superconducting MgB_2 fibers.

Fig. 3 shows energy dispersive x-ray (EDX) data for the cross-sectional data of the MgB_2 fiber. It is clear that Mg diffuse into B fiber. In order to search for the atomic ratio for Mg to B, we used an EDX mapping method. Undiffused region is similar to Figure 2(a). The atomic ratio for Mg/B is plotted in Fig. 4. It shows Mg diffusion, too. It is likely that diffusion rate of Mg is dependent on vapor pressure of Mg and diffusion time, but not yet optimized.

Fig. 5 presents temperature dependent electrical resistance of MgB_2 fibers. Resistance at room temperature MgB2 is 3.745 Ω, and R(40K) = 0.793 Ω and R(77K) = 1.041 Ω. It can be to estimate residual resistivity ratio (RRR) is 3.93. It shows an increase about 1.63 compared to 2.3 in c - axis oriented superconducting MgB2 thin films [4]. And this RRR (=3.93) is less than Finnemore's result that is 20 from sintered pellets of polycrystalline $Mg^{10}B_2$ [5].

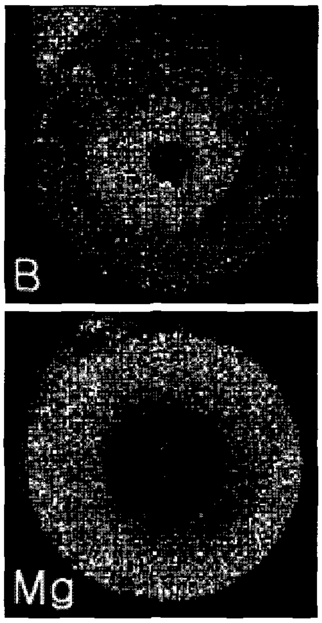

Fig. 3. Scanning and mapping data of a MgB_2 fiber cross-section by EDX measurement.

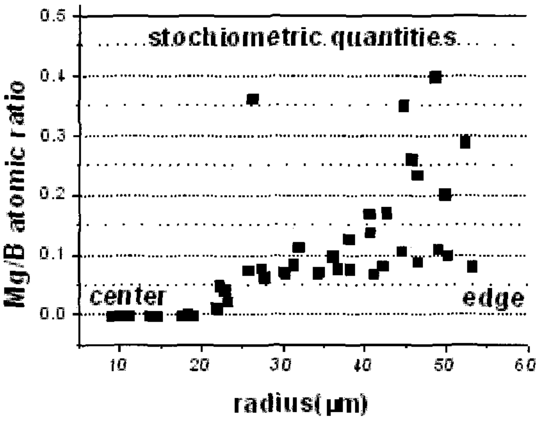

Fig. 4. Mg to B distribution by EDX .

The resistivity of the sintered pellet samples [5] is approximately 1μΩcm at 40K. One of Kim's resistivity is approximately 6 μΩcm [4]. These datum are higher than datum of this study.

We can get $R = R_0 + R_1T^{\alpha}$ with $\alpha \sim 1.49107$ between 40 K and 300 K as shown in Fig. 5. This is comparable to the $\alpha \sim 2.99$ of other study [2] and the power law $R = R_0 + R_1 T^{\beta}$ with $\beta \sim 2.8$ found for the sintered $Mg^{10}B_2$ sample [5]. In the similarity of the two power laws, it seems clear that the resistivity of MgB_2 will not have a linear slope for temperatures between 40 K and 300 K [6]. Critical temperature of MgB_2, T_C = 39.8 K, can be determined from Fig. 5. This value is higher than the T_C = 39.4 K of Canfield et al. [2], 34.5K of Jo et al. [7], and about 38K of Song et al. [8].

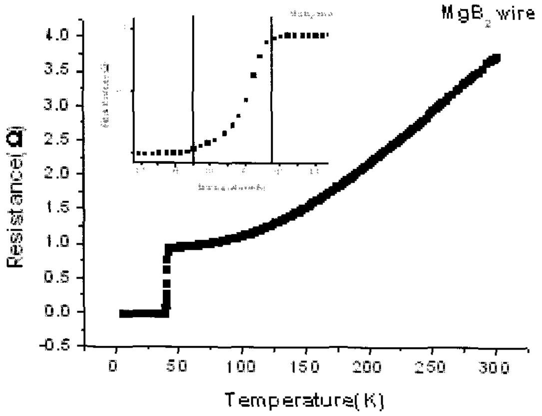

Fig. 5. Resistivity vs. temperature of a MgB_2 fiber.

4. CONCLUSION

We have grown in situ superconducting MgB_2 fiber by Mg diffusion to B fiber in Mg - rich vapor. It shows a superconducting transition at 39.8 K with $\Delta T_C < 2.0$ K. The room temperature resistance has a value of 3.745 Ω, whereas the resistance is 0.793 Ω at 40 K. For the MgB_2 fiber RRR is ~ 4.723. It is clear that Mg diffuse into B fiber by SEM figure. But it dose not perfectly into center. Penetration depth depends on diffusion time and Mg vapor pressure.

ACKNOWLED GMENT

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