Development of MgB_2 wires with an aluminum as a stabilizer

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Al stabilized MgB_2 wire has been prepared by PIT method. Fe was used as a buffer layer between MgB_2 and Al. Segments of Al/Fe-clad wire were sintered at 600-650^{o}C for 30-180 min. Study of Al-Fe diffusion layer and superconducting properties of prepared wires has been presented.

1. Introduction

For thermal stabilization of superconductors a normal metal with high electrical and thermal conductivity, usually Cu or Al, has been used. Use of high purity Al as a stabilizer material offers several advantages over high purity Cu [1-3], such as:

- **High residual resistivity ratio (RRR)**. High purity Al (99.995%) with RRR ~ 5000 is commercially available [2], while high purity coppers (OHFC, C101, >99.99%) have in-service RRRs within the range of 100 to 200 [1, 4]. At applied magnetic fields RRR_{Al} decreases rapidly between 0 and 1 T from 5000 to 4000 and then drops from 4000 at 1T to 1000 at 5T [5]. In case of Cu, RRR_{Cu} decreases more-or-less uniformly from 70 at 0 T to 30 at 5 T. Nevertheless, $RRR_{Al} >> RRR_{Cu}$ over the entire field range 0-5 T.
- **Higher thermal conductivity at low temperatures**. At temperature of 20 K thermal conductivity of Al (99.995%) is 117 W/cm·K, while for Cu (99.99%) – 108 W/cm·K [6].
- **Lower magnetoresistance.** Aluminum has lower magnetiresistance than copper [7]. The rate at which the resistance of aluminum rises with transverse magnetic field diminishes substantially between 1 and 2 T [2], whereas the resistance of copper continues rising at a steep rate. This characteristic makes aluminum favorable in high field environments.
- **Lower density.** The density of Al is approximately 1/3 that of copper (density of Al is 2.70 g/cm^3, density of Cu is 8.86 g/cm^3 [6]). Low density of stabilizing material results in lower weight of superconducting wires or devises.

Recently developed MgB_2 superconducting wires carry a high critical current ($J_c \sim 5\times10^5$ A/cm^2 at 20 K and 0 T [8]), so for practical application it is very important to build up a good thermal stabilization for them. Al appears to be an attractive stabilizer for MgB_2, because it will allow producing cheap and light superconducting wires, suitable for application even in airspace industry. The realization of *in situ* solid-state-diffusion formation of MgB_2 at temperature 600^{o}C [9-11] enables the introduction of Al not only as a stabilizer but also as a support structure of wind-and-react coils.

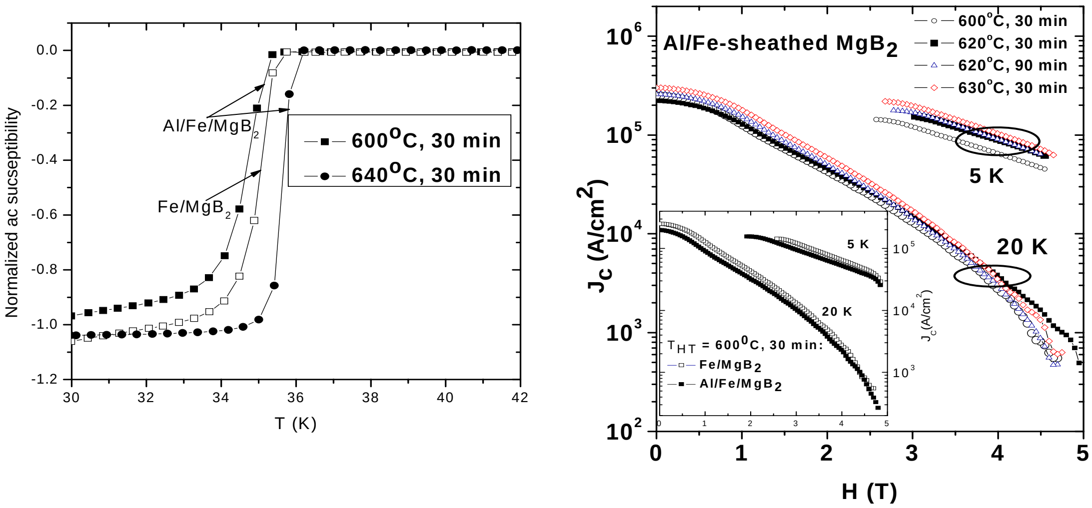
2. Sample preparation

Standard powder-in-tube method and an in-situ reaction technique were used for fabrication the Fe and Fe/Al-clad MgB_2 wires [8, 12]. The Fe tube had an outside diameter (OD) of 10 mm, a wall thickness of 1 mm, and a desired length with one end of the tube sealed. The mixture of magnesium (99%) and amorphous boron (99%) powders was filled into the tube and the remaining end was blocked using an aluminum bar. For fabrication of Al-stabilized/Fe-barrier/MgB_2 wires the Fe/MgB_2 composite was inserted into a pure Al tube which has an inside diameter of 10 mm and a wall thickness of 1 mm (Al alloy 6060 with Al of 99%, Si of 0.5% and Mg of 0.4%). The composite was drawn or groove-rolled to a 1.7 mm OD. Several pieces of this wire were sintered in a tube furnace at 600^{o}C, 620^{o}C, 630^{o}C, 640^{o}C, 650^{o}C for 30min to 3 hours, and finally furnace-cooled to room temperature. A high purity argon gas flow was maintained throughout the sintering process.

3. Results

3.1 Superconducting properties

Fig. 1a shows the transition temperature, T_c, and transition width ΔT_c for MgB_2 samples determined by ac susceptibility measurements. The T_c obtained for the Fe/MgB_2 and Al/Fe/MgB_2 samples annealed at 600^{o}C for 30 min was 35.7 K and 35.4 K, respectively. Increasing of sintering temperature from 600^{o}C to 640^{o}C for 30 min resulted in improving of T_c up to 36.2 K.



a b

Fig.1. a) Transition temperature of Fe/MgB_2 samples with and without Al; b) critical current density of Al/Fe/MgB_2 samples. Insert is comparison of J_c for Fe-barrier MgB_2 samples with and without Al

Fig. 1a shows the magnetic J_c(H) curves at 5K and 20K for the Al/Fe/MgB_2 sintered at 600^{o}C-630 ^{o}C for 30 -90 min. Increasing of sintering temperature resulted in improvement of J_c(H) performance. These results are consistent with those reported previously on pure Fe/MgB_2 wires [8, 10]. Insert in Fig.2a shows J_c(H) for Fe/MgB_2 wire with and without Al. It should be noted that the J_c(H) curves for both the Fe- and Al/Fe-sheathed wires show the same trend, although the former is slightly higher than the latter.

3.2 SEM study

One of major concerns in the use of aluminum as a stabilizer is whether the Al is compatible with Fe barrier. Fig. 2 shows the SEM images for the Al/FeMgB_2 wire as drawn (a), sintered at 600^{o}C for 180 min (b), 620^{o}C for 30 min (c), 620^{o}C for 90 min (d), 640^{o}C for 30 min (e) and 650^{o}C for 30 min (f). It is evident that aluminum and iron remain chemically compatible at annealing temperature of 600^{o}C for 180 minutes and 620^{o}C for 30 min. The Fe/Al interface remains clean and sharp with no evidence of reaction between Fe and Al under these processing conditions. The alloy phase of started to form as a thin layer about 5 μm at sintering temperature of 620^{o}C for 90 min. But the Al_3Fe alloy layer remained small at sintering temperature up to 640^{o}C for 30 min. The Al_3Fe layer grew rapidly at annealing temperature of 650^{o}C for 30 min, resulting in a 100 μm thick interface layer. The formation of Al_3Fe alloy may set the up limit of sintering temperature for processing Fe/Al sheathed MgB_2 as the Al diffusion into Fe layer may reach the MgB_2 core and cause reaction between

Al and MgB_2. However, these results demonstrate that there is a reasonable sintering temperature range from 600°C to 640°C where the formation of Al_3Fe alloy would not cause detrimental effect. Actually, the thin alloy layer may improve the contact between Al and Fe.

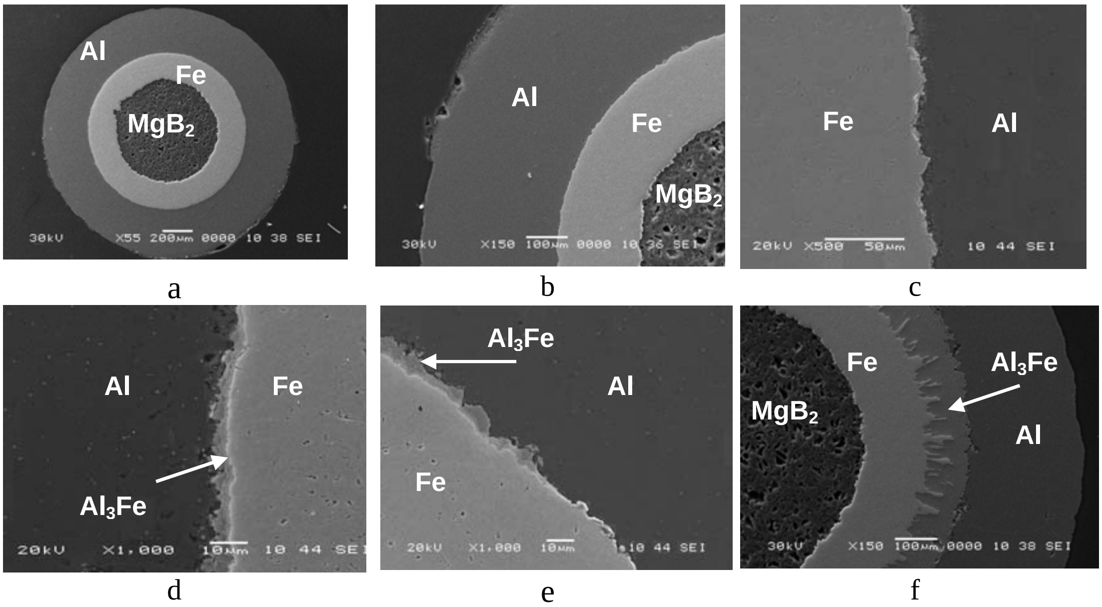


Fig 2. SEM image of the interfaces between Fe and Al sheath for for the Al/Fe/MgB_2 wire a) as drawn and sintered at 600°C for 180 min (b), 620°C for 30 min (c), 620°C for 90 min (d), 640°C for 30 min (e) and 650°C for 30 min (f)

4. Conclusion

In summary we have demonstrated that in Al/Fe-sheathed MgB_2 can be formed by diffusion heat treatments of 600°C-640°C for 30 min. The critical current density and flux pinning behavior of Al/Fe-sheathed MgB_2 wires are comparable to those of Fe-sheathed MgB_2 wire, paving the way for possible use of the lighter and cheaper Al stabilized MgB_2 to replace Cu stabilized superconductors in applications, especially for airborne, aerospace, and other applications where weight is important.

Acknowledgments

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