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Development of MgB₂-based, bulk supermagnets

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A series of disk-shaped, bulk MgB₂ superconductors (sample diameter up to 4 cm) was prepared in order to improve the performance for superconducting supermagnets [1-6]. Several samples were fabricated using a solid state reaction in pure Ar atmosphere from 750 to 950 °C in order to determine the optimum processing parameters to obtain the highest critical current density as well as large trapped field values. The magnetic characterization measurements were performed using SQUID magnetometry (Quantum Design MPMS) and the magneto-resistance and I/V -characteristics were recorded using an Oxford Instruments 8 T Teslatron system.

The MgB₂ sample processed at 775 °C for 3 h showed the highest critical current density of 176 kA cm⁻² and 55 kA cm⁻² at 20 K in self-field and a trapped field of 1 T, respectively. Furthermore, the critical current density values are increasing further to 250 kA cm⁻² and 150 kA cm⁻² on decreasing the temperature further down to 10 K.

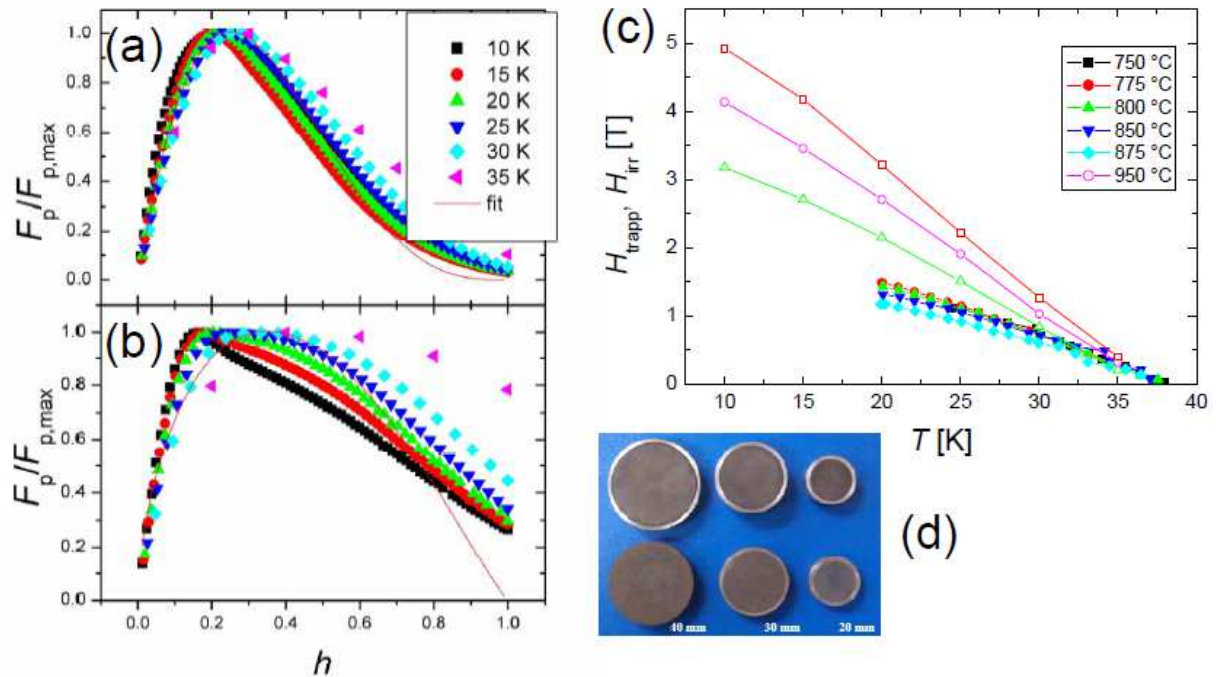


Fig.1 (a,b) Pinning force scaling for the sample prepared at 950 °C (a) and 775 °C (b). The shown fits are fits to all data. The strong non-scaling of (b) is clearly visible. (c) gives the irreversibility lines (open symbols) and the measured trapped fields (full symbols). Finally, (d) illustrates the bulk samples prepared.

The obtained magnetization data were evaluated further and transferred into a pinning force analysis, where the pinning force $F_p = j_c \times B$ is plotted versus a scaling field $h = H_a/H_{irr}$, with H_{irr} denoting the irreversibility field [Figs. 1 (a,b)]. This analysis revealed for the sample prepared at 950 °C a well developed scaling of the normalized pinning force data at low and intermediate temperatures with the scaling parameters $p = 0.65$, $q = 1.35$ and a peak located at $h_0 = 0.32$, indicating pinning at normal conducting precipitates. Similar values are obtained in the literature for small, pure MgB₂ samples. In

contrast to this behavior, the samples prepared at 775 °C and 800 °C reveal a non-scaling: In higher temperatures the peak position shifts to $h_0 = 0.4$, and at low temperatures, a peak position $h_0 < 0.2$ is reached. Such small peak positions cannot be explained by the common scaling model, except that the critical current anisotropy plays a dominating role as shown in Ref. [7]. Here, our data reveal the temperature dependence of this anisotropy factor. The irreversibility lines of several of our samples are plotted in Fig. 1 (c), together with the measured trapped field data. Here it is important to note that the sample prepared at 950 °C shows again a higher irreversibility line as the samples prepared at lower temperatures. This is attributed to the formation of nano-sized MgB₄ particles at the higher reaction temperature, which can provide additional flux pinning.

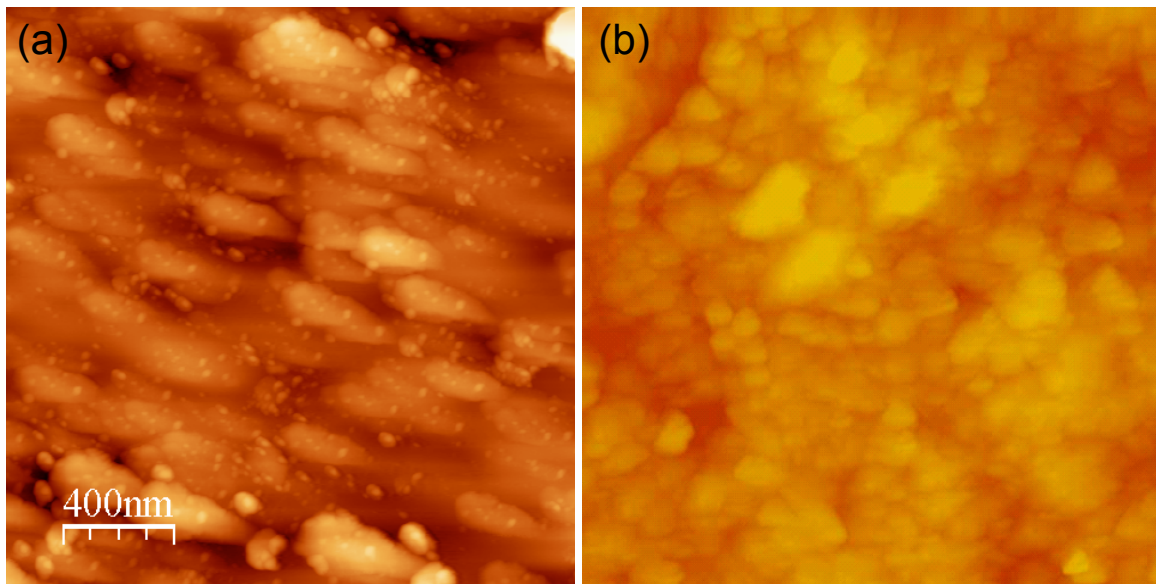


Fig.2 AFM topography images (tapping mode) of the MgB₂ sample prepared at 775 °C (a) and of the sample prepared at 850 °C (b).

Microstructural observations obtained from scanning electron microscopy (SEM) and atomic force microscopy (AFM) indicated that the grain size is the crucial parameter to improve the critical currents as well as the trapped field values. Figure 2 presents typical topographies of the samples recorded in the tapping mode. The images clearly reveal the polycrystalline nature of the sample. Individual MgB₂ grains show a specific shape and have dimensions up to 400 nm. Obviously, the grain size and grain arrangement of (a) represents an optimal configuration, thus leading to the high trapped field values.

Another important aspect for the development of bulk, MgB₂-based supermagnets is the energizing procedure applied. MgB₂ suffers – in contrast to the bulk RE-123 samples – from flux jumps and the specific flux penetration in form of dendrites, especially at low temperatures [8,9]. The magnetization loops measured at 10 K have shown this behavior. Therefore, it will be essential to develop a suited procedure and also measures like a conductive thin-film cover.

As a result, samples of 20 mm in diameter and 7 mm thickness, prepared with optimized processing temperature, exhibited a trapped field of 1.5 T at 20 K. The present results indicate that the continuing development of large size bulk MgB₂, optimum processing, and flux pinning control will encourage numerous new industrial applications.

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