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Bulk superconducting MgB₂: pinning by grain boundaries or point defects?

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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 [1-5]. 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. 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. 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: At 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. [6]. A value of $h_0 = 0.22$ would indicate a dominating flux pinning at grain boundaries, as often reported in the literature [3-5]. The peak positions obtained are shown in Fig. 1 as a function of the measurement temperature (a) and the preparation temperature (b).

In order to clarify the situation of the different contributions to the flux pinning, we performed a thorough microstructure analysis, including atomic force microscopy (AFM) and transmission electron microscopy (TEM). The magnetic data indicated that the grain size r_G

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 by AFM in the tapping mode. The images clearly reveal the polycrystalline nature of the sample. Individual MgB_2 grains show a specific shape and have dimensions up to 400 nm. Obviously, the grain size and the grain arrangement of (a) represents an optimal configuration, thus leading to the high trapped field values. Using TEM, we can directly measure the disturbed surface layers of the grains being responsible for the $1/r_G$ -dependence of the critical current density.

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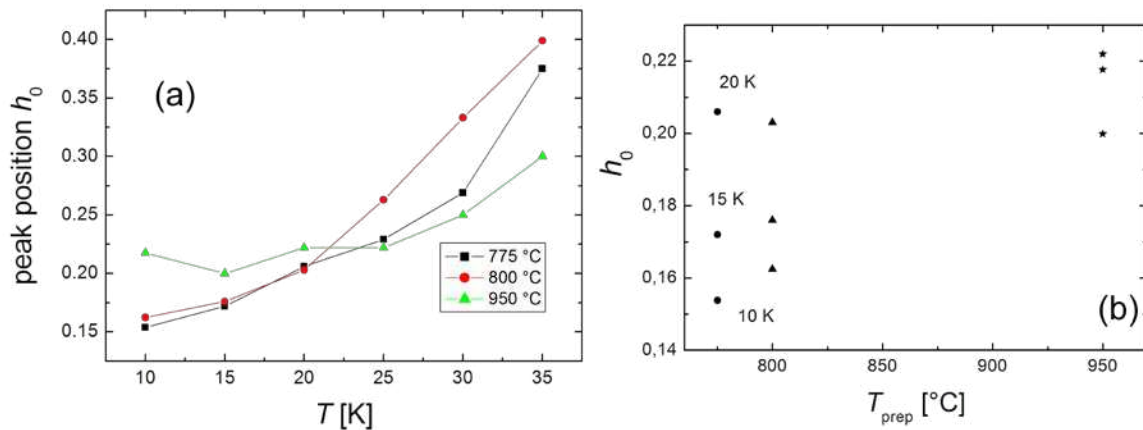


Figure 1: Peak positions, h_0 , measured via the pinning force scaling for the samples prepared at 775 °C, 800 °C and 950 °C. (a) shows the data as function of measurement temperature, (b) as function of the preparation temperature.

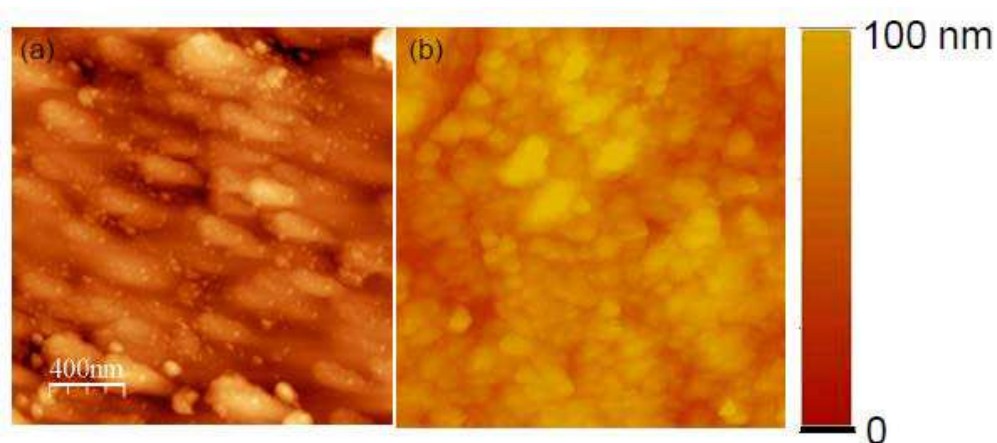


Figure 2: AFM topography images (tapping mode) of the MgB_2 sample prepared at 775 °C (a) and of the sample prepared at 850 °C (b).