Improving Performance in Bulk Magnesium Diboride by Improved Processing

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Introduction

Bulk form magnesium diboride (MgB_2) is a promising material for use in constructing superconducting magnets with operation temperatures up to 20 K, or mid-field magnets (< 10 T) operating at 4.2 K. The processing conditions leading to optimal properties are the object of much investigation. In this work, we examined the effects of carbon alloying, high energy ball milling, and heat treatment temperature on performance (critical current density) and used our results to describe a complex interaction between processing parameters and properties focusing on electron scattering, grain size, lattice composition, and electrical connectivity.

Experimental

Three sample sets (pellets) were synthesized with varying carbon content by a process involving mechanical alloying (in high energy mill) of pre-reacted MgB_2 powder with graphite powder (dopant), followed by hot isostatic pressing. Set A was unmilled and undoped. Set B was milled and undoped. Set C was both milled and doped. One sample from each set was HIP treated at 900°C, 950°C, 1000°C, 1150°C, and 1500°C. The sintered pellets were sectioned with a diamond saw, and their properties investigated. This experiment used the fabrication, characterization, and microscopy facilities located at the Applied Superconductivity Center, as well as the 33 T resistive magnet in the DC field user facility.

Results and Discussion

We found that J_c(H,T) benefited strongly from fine grain sizes <50 nm, available by heat treating at 950°C or lower T. However, sintering was limited below 1000°C causing J_c to be limited by electrical connectivity. In this work we found that high energy milling reduced the T necessary to achieve ~50% of full connectivity from > 950°C to ~900°C in undoped samples. This advance enabled successful heat treatment at 900°C, resulting in an unprecedented combination of connectivity and fine grains (Fig. 1). When beneficial carbon was added to the material, we were able to achieve extremely high J_c (8 T, 4.2 K) > $5x10^4$ A/cm². Further investigation revealed that the benefits of fine grain size are not limited to flux pinning improvement, but to changes in the electron scattering state of the material which result in improvement of the critically important performance-limiting H_{c2}(H//c-axis) with no significant change to H_{c2}(H//ab-plane).

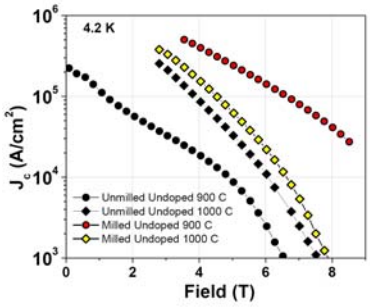

Figure 1 – Critical current density as a function of heat treatment temperature and milling status.

Conclusions

This work simultaneously explored several processing variables and resolved their interrelated effects, resulting in excellent material performance and the knowledge necessary to tailor performance to the temperature and magnetic fields of applications by manipulating heat treatment schedules, mechano-chemical processing, and composition.

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References

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