Investigation of the Magnetic Properties of Novel MgB₂ Thin Films with High $H_{c2}$ Values

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Introduction

The 39 K metallic superconductor MgB₂ [1] has the potential to replace today’s low-$T_c$ materials such as NbTi and Nb₃Sn in commercial high-field magnet applications. Highly crystalline and clean MgB₂ thin films and bulk, however, exhibit relatively small upper critical fields $H_{c2}$ of 15-19 T (||) and 3-5 T (⊥) at 4 K [2-4] (|| and ⊥ refer to the external magnetic field (H) orientation to the MgB₂ a-b plane.). Various methods have successfully enhanced the $H_{c2}$ of MgB₂, including the introduction of carbon, oxygen and SiC, exposure to ion and neutron irradiation, and using MgB₂/MgO multilayer superstructures. Our approach differs from that typically used for MgB₂, where the superconducting phase has been processed at sufficiently high temperatures to be well ordered. In such cases, $H_{c2}(0)$ enhancement is achieved by reduction of the electron mean free path, and of the coherence length, by scattering from impurity defects or secondary phases that are added deliberately. We maximize scattering within the superconducting phase, consistent with achieving an adequate $T_c$.

Experimental

Magnesium plus boron thin films were synthesized on sapphire (0001) substrates in a co-evaporation chamber. Magnesium was evaporated from a Knudsen cell and boron was deposited from an electron-beam evaporation source. To protect the MgB₂ films from further oxidation and magnesium loss during annealing, the materials were covered by ~2000 Å thick SiO₂ layer deposited by Plasma-Enhanced Chemical Vapor Deposition (PECVD).

We found that to achieve a high $T_c$ and $-dH_{c2}/dT|_{T_c}$, magnesium-rich films (Mg₁B₂) and a two step anneal are necessary. This process was found to achieve a high $T_c$ (~30K) while maintaining a high $-dH_{c2}/dT|_{T_c}$ slope (~2.5 T/K). Magnesium deficient films, when exposed to the same heat treatments as magnesium rich samples, attained high $-dH_{c2}/dT|_{T_c}$ values but typically had a very limited $T_c$ (~16 K). The optimized two-step heat treatment of Mg-rich films of Mg plus B grown on unheated substrates can yield $-dH_{c2}/dT|_{T_c}$ value as high as 2.5 T/K, $T_c$ values of ~31 K and $H_{c2}(0)$ values above 43 T. Slopes exceeding 2 T/K were only seen in films with resistivities at 300 K exceeding 2 mΩ cm.

It is of interest to speculate whether the deposition and anneal process described here could be applied to the fabrication of MgB₂ wires. Perhaps, instead of the high temperature anneals generally used today, it would be worthwhile to study two-step low temperature anneals for “powder in tube” wires as well. Rogado et al. have reported that single anneals of bulk mixed powder samples at temperature as low as 550 °C did result in the formation of MgB₂. An outstanding question is whether critical currents in such wires would be large enough to be useful.

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Reference