Title: Processing and characterisation of nano carbon doped MgB2 form of wire and bulk

Author: Wai Kong Yeoh

Year: 2006

Repository DOI:

2006

Processing and characterisation of nano carbon doped MgB2 form of wire and bulk

Wai Kong Yeoh
University of Wollongong

Processing and Characterisation of Nano Carbon Doped MgB_2 in Form of Wire and Bulk

A thesis submitted in fulfillment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

From

UNIVERSITY OF WOLLONGONG

By

Wai Kong Yeoh

Institute for Superconducting and Electronic Materials

2006

DECLARATION

This is to certify that the work presented in this thesis was carried out by the candidate in the laboratories of the Institute for Superconducting and Electronic Materials (ISEM), at the University of Wollongong, NSW, Australia, and has not been submitted for a degree to any other institution for higher education.

Wai Kong Yeoh

2006

ACKNOWLEDGMENTS

I would like to express my since appreciate and thankfulness to my supervisors Prof. S. X. Dou and Dr. J. Horvat for their continuos academic guidance, encouragement and support during my three years PhD study in Institute for Superconducting and Electronic Materials at University of Wollongong.

I would also like to express my gratitude to Prof. H. K. Liu, Dr. X. L. Wang, Dr. M. Ionescu, Dr. K. Konstantinov Dr M. J. Qin and Dr J. H. Kim for their contribution in measurements, the useful discussion and suggestions.

This work wont be completed without the help of Prof. P. R. Munroe from University of New South Wales, Dr Vicki J Keast and Mr. S. Bulcock from University of Sydney, Dr D. Wexler and Dr Z. Chen from Materials Engineering, University of Wollongong, Mr. M. Tomsic from Hyper Tech, USA, Dr. H. Kumakura from NIMS and Mr. S. K. Chen and Dr. K. S. Tan from University of Cambridge for their great collaboration.

My special thanks to all my colleagues at ISEM including Dr. S. Soltanian, Dr. S. Zhou, X. Xu, M. S. Park, S. H. Ng, S. Y. Chew and friends at Richard Johnson College and back home, and all the members and technicians at the Faculty of Engineering especially Mrs. B. M. Allen, Mrs. J. Bistro, Mr. R. Kinnell, Mr. G. Tillman and Mr. N. Mackie for their friendly help and assistance in using the facilities.

I would also like to acknowledge the Department of Education, Science and Training, Australia for providing my PhD scholarship and Miss Cynthia Grant who is my scholarship coordinator for her enthusiastic support.

Finally I wish to thank my parents, my elder brother, my sister in law and my nephew for their patience and support.

Table of Content

List of Figures

List of Tables

ABSTRACT

The objective of this work is to further enhance the critical current density of the MgB_2 superconductor by doping with the two carbon sources: multiwalled carbon nanotube (CNT) and nano carbon. The work in this thesis concentrates on the fabrication and characterization on the CNT and nano C doped MgB_2 with main objective being the enhancement of the critical current density in the high magnetic field. Consequently, introducing effective pinning centres in the form of dopants to enhance the flux pinning will be the main task of this project.

In this project, the effect of carbon doping MgB_2 with carbon nanotubes and nano C on transition temperature, lattice parameters, critical current density and flux pinning for $MgB_{2-x}C_x$ with x = 0, 0.05, 0.1, 0.2 and 0.3 under the various condition was studied. Both types of doping showed excellent J_c compared to the pure MgB_2, with significant enhancement observed at higher temperature. Magnetic $J_c(H)$ was enhanced by a factor of 72 at 5K for a field 8T and a factor of 33 at 20K for a field of 5T for nano C bulk samples, respectively. On the other hand, $J_c(H)$ of CNT samples was enhanced by a factor of 26 and 13 under the equivalent conditions. In high field, transport J_c of magnitude 2122 A/cm^2 and 3821 A/cm^2 was observed at 4.2K and 12T for CNT and nano C doped MgB_2. These results indicate that flux pinning was enhanced by the boron substitution for carbon with increasing processing temperature. However, it was found that the lattice distortion and optimum doping level is different in the CNT and nano C samples which is due to the reactivity of the carbon source, resulting in different carbon substitution rate. Due to better reactivity and homogenous mixing of nano C, nano C doped MgB_2 resulted in better improvement in magnetic and transport $J_c(H)$, as

compared to CNT doped MgB_2. This is mainly because CNT fibres with high aspect ratio tend to entangle, which suppressed the reactivity.

The depression of T_c, which is caused by the boron substitution for carbon, increases with increasing the doping level, processing temperature and duration for both types of carbon doping. By controlling the extent of the substitution and inclusion of carbon, we can achieve the optimal improvement of critical current density and flux pinning in magnetic fields while maintaining the minimum reduction in T_c. In addition, the values of H_{c2} and H_{irr} are higher for CNT doped samples than for the pure MgB_2 at the same value of T/T_c. The morphology of the CNT doped MgB_2 is similar to that of nano C doped MgB_2, but different from the pure MgB_2. The microstructure exhibits noticeable nanoparticles with size around 10-20nm, which are believed to be MgO and MgB_2.

Magnetization measurements indicate a change in the critical current density with the length of nanotube and not with its outside diameter. This is due to longer nanotubes tending to entangle with each other, preventing their homogenous mixing with MgB_2 and dispersion. Low intensity ultrasonication, as a method of dispersion of CNT's into precursor magnesium and boron powder, was introduced to improve homogeneity of mixing of CNT's with the MgB_2 matrix. Ultrasonication of CNT doped MgB_2 resulted in a significant enhancement in the field dependence of critical current density, while avoiding the side-effects that would occur at higher processing temperatures.

Carbon nanotubes (CNT's) have unusual electrical, mechanical and thermal properties. The elongated CNT's induce anisotropy in J_c in relation to the direction of applied field in MgB_2/Fe wires and the value of J_c for the carbon nanotube-doped wires is insensitive to heating rates. We believe that by taking the extraordinary electrical, mechanical and thermal properties of CNT's, the mechanical properties and thermal stability of CNT doped wire will be substantially improved. Studies on these properties are underway.