

2006

## Processing and characterisation of nano carbon doped MgB<sub>2</sub> form of wire and bulk

Wai Kong Yeoh  
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**Processing and Characterisation of Nano Carbon**

**Doped MgB<sub>2</sub> 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

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# Table of Content

<b>Abstract.....</b>	<b>1</b>
<b>Chapter 1 Introduction.....</b>	<b>4</b>
<b>1.1 Introduction.....</b>	<b>4</b>
<b>1.2 References.....</b>	<b>12</b>
<b>Chapter 2: Literature review on MgB<sub>2</sub> superconductor.....</b>	<b>14</b>
<b>2.1 Introduction.....</b>	<b>14</b>
<b>2.2 The Discovery of MgB<sub>2</sub>.....</b>	<b>14</b>
<b>2.3 Crystal and Electronic structure of MgB<sub>2</sub>.....</b>	<b>15</b>
<b>2.4 Electron Phonon Coupling in Superconductivity of MgB<sub>2</sub>.....</b>	<b>19</b>
<b>2.5 Preparation Method.....</b>	<b>21</b>
<b>2.5.1 Bulk MgB<sub>2</sub> superconductor.....</b>	<b>22</b>
<b>2.5.1.1 In-situ Reaction.....</b>	<b>22</b>
<b>2.5.1.2 Hot Isostatic Pressing (HIP).....</b>	<b>23</b>
<b>2.5.1.3 Mechanical alloying.....</b>	<b>25</b>
<b>2.5.2 MgB<sub>2</sub> Superconductor Tape and Wire.....</b>	<b>26</b>
<b>2.5.2.1 Powder in Tube (PIT).....</b>	<b>26</b>
<b>2.5.3 Alternative Preparation Routes.....</b>	<b>29</b>
<b>2.6 Basic Properties of MgB<sub>2</sub>.....</b>	<b>31</b>
<b>2.6.1 Critical Temperature, T<sub>c</sub>.....</b>	<b>31</b>
<b>2.6.2 Critical current, I<sub>c</sub> and Flux Pining.....</b>	<b>32</b>
<b>2.6.3 Crystallinity and Grain Size effect on Critical Current Density.....</b>	<b>35</b>

2.6.4	Effect of Mg precursor powder on MgB <sub>2</sub> Superconductivity...	36
2.6.5	Effect of boron precursor powder on Superconductivity.....	37
2.6.6	Porosity and Density Effect.....	38
2.7	Effect on Chemical Doping on MgB <sub>2</sub> Superconductivity.....	39
2.7.1	Carbon doping.....	39
2.7.2	Carbon Nanotube (CNT) doping.....	44
2.7.3	Metal Doping.....	47
2.7.3.1	Al doping.....	47
2.7.3.2	Zn doping.....	48
2.7.3.3	Au doping.....	48
2.7.3.4	Cd doping.....	48
2.7.3.5	Ti doping.....	49
2.7.3.6	Fe doping.....	50
2.7.3.7	La doping.....	50
2.7.3.8	Zr doping.....	50
2.7.3.9	Ta doping.....	51
2.7.3.10	Other metal doping.....	51
2.7.4	Oxide and other compound Doping.....	52
2.7.4.1	Al <sub>2</sub> O <sub>3</sub> doping.....	52
2.7.4.2	Bi-2212 doping.....	53
2.7.4.3	Fe <sub>2</sub> O <sub>3</sub> doping.....	53
2.7.4.4	MgO doping.....	53
2.7.4.5	Silicides doping.....	54
2.7.4.6	SiO <sub>2</sub> doping.....	54

2.7.4.7 Nb <sub>x</sub> B <sub>2</sub> doping.....	55
2.7.4.8 Mg <sub>2</sub> Cu doping.....	55
2.7.4.9 O <sub>2</sub> doping.....	55
2.7.4.10 TiO <sub>2</sub> doping.....	56
2.7.4.11 ZrB <sub>2</sub> doping.....	56
2.7.4.12 ZrO <sub>2</sub> doping.....	56
2.7.4.13 ZrH <sub>2</sub> doping.....	57
2.7.4.14 WB doping.....	57
2.7.4.15 Y <sub>2</sub> O <sub>3</sub> doping.....	57
2.7.4.16 Dy <sub>2</sub> O <sub>3</sub> doping.....	58
2.8 Practical Applications and challenges of MgB <sub>2</sub> .....	60
2.9 References.....	65
Chapter 3: Experimental.....	86
3.1 Bulk sample preparation.....	86
3.2 Fabrication of MgB <sub>2</sub> Wire and Tape.....	87
3.3 Samples Characterizations.....	88
3.3.1 X-ray Diffraction (XRD).....	88
3.3.2 Scanning electron microscopy (SEM) and Energy dispersive x-ray spectrometry (EDS).....	88
3.3.3 Transmission Electron Microscopy (TEM).....	89
3.3.4 Critical Current Density, T <sub>c</sub> , Measurements.....	90
3.3.5 Critical Current Density, J <sub>c</sub> , Measurements.....	91
3.3.6 Upper Critical field, H <sub>c2</sub> and Irreversibility Field, H <sub>irr</sub> .....	93
3.3.7 References.....	94



<b>Chapter 4: Strong pinning and high critical current density in carbon nanotube doped MgB<sub>2</sub>.....</b>	<b>95</b>
4.1 Introduction.....	95
4.2 Experimental.....	97
4.3 Results and Discussions.....	99
4.4 Conclusion.....	114
4.5 References.....	115
<b>Chapter 5: Effect of Dimensions of Carbon Nanotube on MgB<sub>2</sub> and Improving the Flux Pinning by Ultrasonication.....</b>	<b>118</b>
5.1 Introduction.....	118
5.2 Experimental.....	121
5.3 Results and Discussions.....	122
5.3.1 Comparison of CNT with different dimensions.....	122
5.3.2 Dispersion of CNT's by Ultrasonication .....	128
5.4 Conclusion.....	133
5.5 References.....	134
<b>Chapter 6: Enhanced Performance of MgB<sub>2</sub>/Fe Superconducting Wires prepared by In-situ Method with Carbon Nanotube addition.....</b>	<b>136</b>
6.1 Introduction.....	136
6.2 Experimental.....	137
6.3 Results and Discussions.....	138
6.4 Conclusion.....	145
6.5 References.....	145

<b>Chapter 7: Control of Nano Carbon Substitution for Enhancing the Critical Current Density in MgB<sub>2</sub>.....</b>	<b>147</b>
<b>7.1 Introduction.....</b>	<b>147</b>
<b>7.2. Experiment.....</b>	<b>148</b>
<b>7.3 Results and Discussions.....</b>	<b>149</b>
<b>7.4 Conclusion.....</b>	<b>158</b>
<b>7.5 References.....</b>	<b>159</b>
<b>Chapter 8 Conclusions.....</b>	<b>162</b>
<b>Publications.....</b>	<b>165</b>

## List of Figures

Figure 1.1	Evolution of $T_c$ with time.....	5
Figure 2.1	Crystal structure of $MgB_2$ [14].....	16
Figure 2.2	Electronic structure of $MgB_2$ (a) the 2-D network of $\sigma$ bands and 3-D network of $\pi$ bands [23] (b) Fermi surface of $MgB_2$ . The vertical sections of cylinders at the corners are associated with the $\sigma$ bands; the more 3 D network of tunnels and caves in the centres of the zone is associated with $\pi$ bands. ([19]).....	18
Figure 2.3	Boron Isotope Effect in Superconducting $MgB_2$ [37].....	20
Figure 2.4	Phase Diagram of Mg+B [48].....	23
Figure 2.5	Magnetization critical current density $J_c$ as a function of magnetic field $H$ for the non-HIPed and HIPed samples at 5 and 30 K. The $J_c$ at 0 field is nearly the same for both samples, but the differences between the samples increases with field, and the drop in $J_c$ at higher fields is remarkably faster in the non-HIPed sample than in the HIPed one [53].....	24
Figure 2.6	SEM micrographs of $MgB_2$ samples (a) surface of the non-HIPed and (b) surface of HIPed sample[53].....	24
Figure 2.7	Process of Powder In Tube (PIT) for in-situ and ex-site method.....	27
Figure 2.8	$MgB_2$ wire segments made from 100 $\mu m$ diameter boron filaments [95].....	29
Figure 2.9	Schematic of the continuous tube filling/forming (CTFF) process...	30
Figure 2.10	The field dependence of $J_c$ for $MgB_2$ samples doped by 10 wt% of different SiC powders as well as the reference sample at different temperatures of 5, 20 and 30 K [101].....	35
Figure 2.11	Theoretical concept of “in-situ” reaction of Mg and B [1].....	39
Figure 2.12	Variation of the actual carbon substitution plotted against the nominal carbon content in the $MgB_{2-x}C_x$ [141].....	41
Figure 2.13	Significant enhancement of transport $J_c(H)$ by SiC doping [75].....	44
Figure 2.14	Comparison of $J_c$ of $MgB_2$ with other commercial superconducting wires [236]. All results were measured at 4.2 K unless labelled otherwise .....	62

Figure 2.15	MgB <sub>2</sub> wires cost less than those based on copper or high-temperature superconductors [237].....	63
Figure 3.1	Schematic diagram of mutual inductance technique for measuring the critical temperature.....	91
Figure 3.2:	Magnetic hysteresis loop showing the width of the magnetic hysteresis loop $\Delta M$ .....	93
Figure 3.3	(a) resistivity method to measure the $H_{c2}$ and $H_{irr}$ (b) $H_{irr}$ determined by using the criteria of $J_c = 100 \text{ A/cm}^2$ (c) Magnetization method to determine the $H_{c2}$ .....	94
Figure 4.1	XRD pattern for carbon nanotube doped MgB <sub>2-x</sub> C <sub>x</sub> with $x = 0, 0.05, 0.1, 0.2$ and $0.3$ , processed at $800^\circ\text{C}$ for 30 min.....	100
Figure 4.2:	XRD pattern of (002) and (100) peak for carbon nanotube doped MgB <sub>2-x</sub> C <sub>x</sub> with $x = 0, 0.05, 0.1, 0.2$ and $0.3$ .....	100
Figure 4.3:	Variation of lattice parameter $a$ and unit cell volume of MgB <sub>2-x</sub> C <sub>x</sub> , for nominal $x = 0.2$ , with processing temperature. The carbon was in the form of multi-walled carbon nanotubes. Inset: XRD pattern for carbon nanotube doped MgB <sub>2</sub> , sintered at temperatures as indicated in the Figure. Symbols * and # indicate the XRD peaks for MgB <sub>2</sub> and MgO, respectively.....	102
Figure 4.4.	Difference in lattice parameter $a$ as a function of transition temperature for CNT doped MgB <sub>2</sub> samples.....	103
Figure 4.5	Magnetic AC susceptibility as a function of temperature for MgB <sub>2-x</sub> C <sub>x</sub> sintered at different temperatures for 30 minutes.....	104
Figure 4.6.	Critical current density as a function of magnetic field at 5K and 20K for different doping level of multi-walled carbon nanotubes.....	105
Figure 4.7.	Critical current density as a function of magnetic field at 5K and 20K for MgB <sub>1.8</sub> C <sub>0.2</sub> , sintered at different temperatures for 30 minutes. The carbon was in the form of multi-walled carbon nanotubes.....	106
Figure 4.8.	Irreversibility field for $H_{irr}$ as a function of processing time for MgB <sub>1.8</sub> C <sub>0.2</sub> sintered at 900 and 1000 °C. $H_{irr}$ obtained from $\Delta M(H)/V = 0.1\Delta M(0)/V$ is shown by triangles. $H_{irr}$ obtained from $\Delta M(H)/V = 0.1\Delta M(0)/V$ , but only for the screening around the whole of the sample, is shown by squares. The inset shows $H_{irr}$ taken with the commonly used criterion of $J_c = 100 \text{ A cm}^{-2}$ . For more detail please refer to [27].....	107
Figure 4.9.	(a) Resistivity vs temperature for undoped and doped sample from 300K to 30K. (b) shows the transition near $T_c$ .....	109

Figure 4.10. Temperature variation of electrical resistivity in magnetic field $H = 0, 0.25, 0.5, 1, 2, 3, 4, 5, 6, 7$ and $8.7$ T for pure $MgB_2$ and $MgB_{1.8}C_{0.2}$ .....	110
Figure 4.11. Normalized temperature ( $T/T_c(0)$ ) dependence of the upper critical field, $H_{c2}$ , for pure $MgB_2$ and $MgB_{1.8}C_{0.2}$ . with both processed at $900^\circ C$ . Inset: the same dependence, but versus the temperature.....	111
Figure 4.12. SEM images of (a) pure $MgB_2$ (b) $MgB_{1.8}C_{0.2}$ sintered at $750^\circ C/30min$ (c) $MgB_{1.8}C_{0.2}$ sintered at $900^\circ C/30min$ (d) $MgB_{1.8}C_{0.2}$ sintered at $1000^\circ C/30min$ .....	112
Figure 4.13. TEM images of CNT that was doped into the samples processed at $750^\circ C$ (a) and $900^\circ C$ (b) for $MgB_{1.8}C_{0.2}$ .....	113
Figure 5.1 TEM images of carbon nanotube with 8-15nm diameter under high magnification.....	120
Figure 5.2 X-ray diffraction pattern of different diameter size carbon nanotubes that were sintered at $900^\circ C$ for 30 minutes.....	122
Figure 5.3 Critical temperature, $T_c$ as a function of change of lattice parameter $a$ . Reference sample is also included as comparison. All the samples were processed at $900^\circ C$ for 30min.....	123
Figure 5.4 TEM image showing the carbon nanotube embedded into the $MgB_2$ matrix for (a) carbon nanotube with diameter 8-15nm and (b) carbon nanotube with diameter 20-30nm.....	124
Figure 5.5 A comparison of magnetic $J_c(H)$ at 5K and 20 K for all the carbon nanotube doped samples and the pure $MgB_2$ .....	125
Figure 5.6 TEM image showing agglomeration of carbon nanotube in $MgB_2$ with nanotube diameter 8-15nm.....	125
Figure 5.7 Dependence of $J_c$ as a function of the average length of nanotubes incorporated into the $MgB_2$ matrix. The solid line through the points is guide to the eye.....	127
Figure 5.8: Variation of critical temperature with the unit cell volume of CNT doped $MgB_{1.8}C_{0.2}$ .....	129
Figure 5.9: Critical current density as a function of applied magnetic field at 5 K and 20 K for both normal grinding and ultrasonicated after grinding $MgB_2$ doped (a) 10at. % of OD < 8nm CNT, (b) 10at. % of OD 8-15 nm CNT, (c) CNT 10% and at. 5% of OD 20-30 nm CNT and (d) 10at. % of OD 60-100 nm...	130

- Figure 5.10: TEM image showing the carbon nanotube embedded into the MgB<sub>2</sub> matrix for carbon nanotube in (a) & (b) the normal grinding samples with the circles show agglomeration of carbon nanotubes (b) the normal grinding and ultrasonication sample with circles showing a good dispersion of carbon nanotubes.....131
- Fig. 6.1 Critical current density as a function of applied magnetic field at 5 K and 20 K for the undoped and CNT doped MgB<sub>2</sub> wires processed at 800°C for 30 min. All the samples made for magnetic measurement have the same dimension of 0.7mm OD and 2.7mm in length. The measurement field  $H$  was applied perpendicular and parallel to the wire axis,  $a$ , during the measurement of  $M-H$  loops.....139
- Fig. 6.2 (a) FIB-SEM micrographs of the CNT doped MgB<sub>2</sub> wire core processed at 800°C for 30 min, showing the elongated macrostructure along the wire axis, (b) Transmission electron micrographs (TEM) for the CNT doped MgB<sub>2</sub> pellet processed at 800°C for 30 min. showing the entangled CNT's randomly distributed in the MgB<sub>2</sub> matrix, (c) TEM image for the CNT doped MgB<sub>2</sub> wire processed at 800°C for 30 min. showing bundled CNT's in the one direction in the MgB<sub>2</sub> matrix. The inset in Fig 2 (c) is the high resolution image of CNT, and (d) TEM image for several parallel CNT's embedded in MgB<sub>2</sub>. The inset in Fig 2 (d) is the high resolution lattice image of one of CNT's.....140
- Figure 6.3 Critical current density,  $J_c$  as a function of magnetic field at 6 and 20K for pure and CNT doped MgB<sub>2</sub>/Fe wires annealed at 650 °C or 850 °C for 30 min with two different heating rates of 100 °C/h and 900 °C/h.....142
- Figure 6.4 The DTA curves for the undoped and CNT doped MgB<sub>2</sub> wires processed with heating rate of 15°C/min.....143
- Figure 7.1 (a) XRD data for various carbon doped bulk samples sintered at 900°C for 30min. (b)Variation of lattice parameters  $a$  for various carbon doping levels in bulk MgB<sub>2</sub>.....150
- Figure 7.2: The magnetic  $J_c(H)$  curves at 5K and 20K for the samples of bulk MgB<sub>2-x</sub>C<sub>x</sub>, where  $x = 0, 0.05, 0.1, 0.2$  and  $0.3$ . Inset shows the critical temperature ( $T_c$ ) for the samples with 2.5-15 at% C that was sintered at 900 and 1000°C for 30 min.....150
- Figure 7.3: Magnetic  $J_c(H)$  for bulk MgB<sub>1.9</sub>C<sub>0.1</sub> samples with various processing temperature.....152
- Figure 7.4: (a) TEM image and (b) the EDX elemental mapping for carbon doped bulk MgB<sub>2</sub>. Grey image is the original TEM image with brighter area indicating higher concentration for Mg, O and C, respectively.....153
- Figure 7.5: Comparison of magnetic  $J_c(H)$  for bulk nano carbon and CNT samples sintered at 900°C for 30 min.....154

Figure 7.6 <110> peak of the XRD pattern for nano C and CNT samples.....156

Figure 7.7 Transport  $I_c$  for nano C and CNT at 4 K prepared various processing temperatures.....157

## List of Tables

Table 2.1: Superconducting transition temperatures of Al-B <sub>2</sub> type boride superconductors .....	15
Table 2.2 Comparison of magnetic and transport $J_c(H)$ at 4 and 20K for different carbon doping sources. All the $J_c(H)$ were determined by the magnetization unless stated.....	46
Table 2.3 Comparison of magnetic and transport $J_c(H)$ at 4.2/5K and 20K for other sources of inclusion doping . All the $J_c(H)$ were determined by the magnetization unless stated.....	58
Table 3.1 Details of various precursors materials used in this work.....	87
Table 5.1 Outside diameter and length of carbon nanotubes used.....	120
Table 5.2: Variation of outside diameter, length of CNT, critical temperature and density of the sample for the CNT doped MgB <sub>2</sub> prepared by normal grinding and ultrasonication .....	129



## ABSTRACT

The objective of this work is to further enhance the critical current density of the MgB<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> with carbon nanotubes and nano C on transition temperature, lattice parameters, critical current density and flux pinning for MgB<sub>2-x</sub>C<sub>x</sub> 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<sub>2</sub>, 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<sup>2</sup> and 3821 A/cm<sup>2</sup> was observed at 4.2K and 12T for CNT and nano C doped MgB<sub>2</sub>. 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<sub>2</sub> resulted in better improvement in magnetic and transport  $J_c(H)$ , as

compared to CNT doped MgB<sub>2</sub>. 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<sub>2</sub> at the same value of  $T/T_c$ . The morphology of the CNT doped MgB<sub>2</sub> is similar to that of nano C doped MgB<sub>2</sub>, but different from the pure MgB<sub>2</sub>. The microstructure exhibits noticeable nanoparticles with size around 10-20nm, which are believed to be MgO and MgB<sub>2</sub>.

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<sub>2</sub> 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<sub>2</sub> matrix. Ultrasonication of CNT doped MgB<sub>2</sub> 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<sub>2</sub>/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.