UNIVERSITI PUTRA MALAYSIA

SUPERCONDUCTING PROPERTIES OF MgB_2 AFTER REACTION WITH SILICON AND CARBON-CONTAINING ADDITIVES

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SUPERCONDUCTING PROPERTIES OF MgB2 AFTER REACTION WITH SILICON AND CARBON-CONTAINING ADDITIVES

By

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SiC is one of the promising dopants that effectively improves the critical current density (Jc) of MgB2 by substituting C into B-site and enhances electron scattering. However, the roles of Si and C in influencing the superconducting properties of MgB2 are not fully understood. Furthermore, systematic study on the optimum dopant addition level and effect of sintering temperature are required in order to provide further insight into how SiC or both Si and C enhance Jc. In this study, nano-SiC and combination of nano-Si and nano-C (Si+C) that made of similar ratio to that of SiC [up to 15 weight percentage (wt.%)] was reacted with Mg+B powder by *in situ* solid state method. These bulks were sintered at 650°C and 850°C, respectively. Characterizations are performed by using Xray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Magnetic Property Measurement System (MPMS). These samples were compared in terms of phase formation, lattice properties, microstructure and superconducting properties.

At 650°C, samples reacted with SiC show smaller *a*-axis and more vigorous lattice distortion because of higher C substitution at B site as compared to same amount of

(Si+C) addition. This is due to the reactive form of C atoms released from Mg-SiC

reaction with lower Gibbs free energy. Higher C substitution in SiC reacted sample results in more severe degradation in superconducting transition temperature (Tc) arising from more severe lattice distortion. Samples reacted with SiC (up to 5 wt.%) show stronger improvement in Jc at both 5 K and 20 K mainly because of smaller grains that enhance grain boundary pinning and degraded crystallinity due to lattice defect.

At 850°C, (Si+C) reacted samples have greater extent of *a*-axis contraction and more severe lattice distortion because of higher C substitution than those samples reacted with SiC. Such phenomenon is probably due to the availability of more C in which separate Si and C particles are used or effect of higher sintering temperature. Higher level of C substitution in (Si+C) reacted samples leads to more severe Tc suppression because of more severe lattice distortion. On the other hand, (Si+C) reacted samples show stronger Jc improvement at both 5 K and 20 K due to higher C substitution at B-site that further enhances electron scattering.

As a conclusion, for sintering at 650°C, reaction of SiC with MgB2 is preferred while sintering at 850°C, reaction of (Si+C) with MgB2 is favored as higher C substitution and more lattice defects occur in these samples which effectively enhance the Jc. Among all samples, the Jc of 5 wt.% SiC reacted MgB2 at 650°C, as compared to the pure sample, is improved by a factor of two at 5 K for the applied field of 6 T and 60 % more at 20 K for the applied field of 4 T, respectively. This improvement is due to degraded crystallinity and higher C substitution that further scatter the electrons and smaller grains that enhance grain boundary pinning.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan untuk ijazah Master Sains

SIFAT-SIFAT KESUPERKONDUKTORAN MgB2 SELEPAS BERTINDAK BALAS DENGAN BAHAN TAMBAHAN MENGANDUNGI SILIKON DAN KARBON

Oleh

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SiC adalah salah satu dopan yang dapat meningkatkan ketumpatan arus genting (Jc) MgB2 secara berkesan dengan menggantikan C ke dalam tapak B dan juga meningkatkan penyebaran elektron. Tetapi, fungsi Si dan C dalam mempengaruhi sifatsifat kesuperkonduktoran MgB2 belum difahami sepenuhnya. Tambahan pula, kajian yang sistematik terhadap penambahan dopan optimum dan kesan suhu pemanasan adalah diperlukan agar memberi pandangan mendalam terhadap bagaimana SiC atau kedua-dua Si dan C dapat meningkatkan Jc. Dalam kajian ini, nano-SiC atau kombinasi nano-Si dan nano-C berasingan (Si+C) yang dicampur pada nisbah yang sama kepada SiC [sehingga 15 peratus keberatan (wt.%)] telah ditindak-balas dengan serbuk Mg+B secara kaedah keadaan pepejal *in situ*. Sampel-sampel ini dipanaskan pada 650°C and 850°C secara berasingan. Pencirian sampel dijalankan dengan pembelauan sinar X (XRD), mikroskopi imbasan elektron (SEM) dan sistem penyukuran sifat magnetik (MPMS). Sampel-sampel ini telah dibandingkan dari segi pembentukan fasa, sifat kekisi, mikrostruktur dan sifat kesuperkondukturan.

Pada 650°C, sampel yang bertindak balas dengan SiC menunjukkan paksi-*a* yang lebih

kecil, struktur kekisi yang lebih herot disebabkan penggantian C ke dalam B yang lebih tinggi ke dalam tapak B jika dibandingkan dengan penambahan (Si+C) yang sama tahap. Ini adalah kerana C atom yang lebih reaktif dibebaskan dari tindak-balas Mg-SiC dengan tenaga bebas Gibbs yang lebih rendah. Penggantian C yang tinggi dalam sampel juga memberikan kesan penurunan suhu genting (Tc) yang lebih serius oleh kerana herotan kekisi yang nyata. Sampel yang bertindak balas dengan SiC (sehingga 5 wt.%) menunjukkan peningkatan Jc yang lebih baik pada 5 K dan 20 K disebabkan lebih banyak butiran kecil yang meningkatkan pengepinan sempadan butiran dan kehabluran yang ternyahgred akibat kecacatan kekisi.

Pada 850°C, sampel yang bertindak balas dengan (Si+C) mempunyai susutan paksi-*a* yang lebih teruk dan kekisi yang lebih herot disebabkan penggantian C ke dalam B yang lebih banyak dibandingkan dengan sampel yang bertindak-balas dengan SiC. Ini adalah kerana terdapatnya lebih banyak C dengan menggunakan Si dan C yang berasingan dan penggantian yang digalakkan oleh suhu pemanasan yang lebih tinggi. Penggantian C yang lebih tinggi dalam sampel yang bertindak balas dengan (Si+C) turut menyebabkan penurunan Tc yang lebih nyata kerana kekisinya lebih herot. Akan tetapi, peningkatan Jc pada 5 K dan 20 K telah ditunjukkan dalam sampel yang bertindak balas dengan (Si+C) akibat penggantian C yang lebih banyak untuk penyebaran elektron.

Secara kesimpulan, bagi pemanasan pada 650°C, MgB2 adalah digalakkan bertindak balas dengan SiC untuk mendapat Jc yang lebih tinggi manakala untuk pemanasan pada 850°C, MgB2 adalah digalakkan bertindak balas dengan (Si+C) kerana penggantian C yang lebih banyak untuk menyebarkan elektron dan kecacatan kekisi yang lebih nyata ditunjukkan dalam sampel-sampel tersebut. Sekiranya dibandingkan dengan sampel tulen, peningkatan Jc yang ditunjukkan dalam sampel yang bertindak balas dengan 5 wt.% SiC pada 650°C, adalah sebanyak dua kali ganda pada 5 K, 6 T dan 60 % lebih banyak pada 20 K, 4 T dalam keadaan suhu dan medan magnetik berlainan. Ini adalah disebabkan kehabluran yang lebih nyahgred dan penggantian C yang lebih banyak untuk menyabarkan lagi elektron serta butiran lebih kecil yand meningkatkan lagi pengepinan sempadan butiran.

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I certify that an Examination Committee has met on 2nd November 2011 to conduct the final examination of Tan Kwee Yong on his thesis entitled “Superconducting properties of MgB_2 Reacted with Silicon and Carbon-Containing Additives” in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 march 1998. The Committee recommends that the student be awarded the Master of Science.
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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

TAN KWEE YONG
Date: 2nd November 2011

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