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Cover picture: A kaleidoscope picture of transition metal doped In$_2$O$_3$ single crystal grown by PbO flux method. (G. Peleckis)
The picture is taken after the talk given by Professor G. Ramanath

Front row: (left to right) Dr. J. Yang, Dr. Z. P. Guo, L. Lu, Dr. G. Peleckis, Dr. D. M. Han, Dr. Z. M. Zou, S. H. Ng
Second row: (left to right) Dr. F. Gao, J. Yao, S. Y. Chew, R. Nigam, O. Shcherbakova, Dr. J. Z. Wang, Prof. H. K. Liu, L. Yuan
Third row: (left to right) Dr. R. Zeng, D. Beucher, Dr. X. L. Gou, A. Ranjbar, Prof. S. X. Dou, Prof. G. Ramanath, Assoc. Prof. X. L. Wang, B. Winton, Z. Huang, Prof. C. Zhang, S. L. Chou
People at the back: (left to right) Z. W. Zhao, Dr. J. Wang, Dr. Z. X. Cheng, J. S. Park, X. Xu, Dr. W. K. Yeoh, M. S. A. Hossain, Dr. J. Horvat, Dr. K. Konstantinov, Dr. G. X. Wang, W. Li, A. Shcherbakov, Prof. R. A. Lewis, Dr. S. Zhou, Q. Yao, Dr. C. H. Jiang
Who’s missing? Dr. C. Freeth, Dr. A. Martin, Dr. A. V. Pan, Dr. D. Q. Shi, Dr. T. M. Silver, A/Prof R. Vickers, Dr. Y. Zhao, M. Farhoudi, D. Chen, K. de Silva

Our Mission -

To establish and maintain a world-class co-operative research team in superconducting and electronic materials science and technology and stimulate the technological and commercial development of Australian Industry in this field.
Vice-Chancellor’s Award for Outstanding Service for General Staff

The Vice-Chancellor’s awards recognize the outstanding contributions staff make to the University of Wollongong. The Vice-Chancellor’s Award for Outstanding Service is presented each year to members of general staff who have achieved an exceptional success, given outstanding service and shown recognized initiative in their work.

This year ISEM’s technical officer – Ron Kinnel received the award. Ron has made a valuable contribution to ISEM in many areas of his work. He has worked tirelessly on the helium liquefier, which has excellent cost savings for ISEM and he services 10 laboratory areas and helps more than 40 postgraduate students and research staff.

VC’s Award for Outstanding Service for General Staff

Ron Kinnell
ISEM Postgraduate Student Awards

Each year ISEM selects a number of outstanding students and in recognition of their research efforts, these students are presented with a Certificate to mark their achievements, together with a cash prize.

Postgraduate Student Excellence Award 2006

See How (Desmond) Ng
Excellence Award

Wai Kong Yeoh
Excellence Award

Postgraduate Student Merit Award 2006 & Best Paper Award

Rashmi Nigam
Merit Award

Germanas Peleckis
Best Paper Award
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Professor Chao Zhang  
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2006 is the last year of the Three Year Plan (2004-2006) of the University’s Research Strength Program, which has identified the Institute for Superconducting and Electronic Materials (ISEM) as one of the key research strength areas. We continued to improve our research environment and facilities, as well as personnel to pursue the numerical target for the three years, which is ten ARC fellows, twenty full time researchers, forty postgraduate students enrolled, 50% of papers published in journals with an impact factor greater than 2 and $2m ARC funding per year. We have surpassed almost all of these targets with eleven various ARC fellows and more than twenty full time researchers and academics. We’ve been very active in terms of publishing 97 journal articles and more than half of those in journals with impact factors greater than 2. We had thirty two enrolled postgraduate students and are confident about increasing this number in 2007. Lastly our total ARC funding obtained in the 2006 round exceeded $2.5 million, with total funds exceeding $3.3 million.

Major progress has been made in several of our key research areas. We have continued our unremitting research efforts on superconductivity in magnesium diboride. We found that nano-dopants containing carbon, SiC in particular, improve both vortex pinning and the upper critical field. We have shown that carbon gets released from nano-SiC at around 600 ºC, when Mg powder reacts with SiC, producing Mg₂Si. At the same time MgB₂ is formed. This freshly made carbon is chemically very active and occupies some of the boron sites in MgB₂. Thus, vortex pinning is introduced into the MgB₂ superconductor. We’ve also found that doping of MgB₂ with carbohydrates, such as sugar or sucrose, in a liquid phase, provides an efficient and desirable method of homogeneous, inexpensive, and degradation-free mixing with host precursor materials. This approach results in atomic-scale coating of each B-particle by sugar, which enables efficient homogeneous doping. The application of this method to MgB₂ has led to an enhancement of in-field $J_c$ by more than an order of magnitude. In spintronics, very interesting results have been observed in YBCO/LSMO/YBCO thin film heterostructures. Our structures showed large magnetoresistance at high temperatures, with sharp switching between the high and low resistance states, which we assume correspond to antiparallel and parallel alignment of the moments of these hybrid structures. Room temperature ferromagnetism and large positive magnetoresistance were also found in Mn-Fe, Mn, Ni-doped indium oxide, and indium tin oxide. In energy storage research, spheroidal carbon-coated Si nanocomposite, prepared by a spray-pyrolysis method in air, is a promising candidate for use as an anode material in lithium ion batteries, as it has excellent retention of specific capacity of 1489 mAhg⁻¹ after 20 cycles and 1120 mAhg⁻¹ after 100 cycles, high coulombic efficiency, and low cost. Functional metal oxide powders have been synthesized by a novel Electric Discharge Assisted Mechanical Milling (EDAMM) processing technique. The EDAMM technique provides significant commercial opportunities, as the method has proven to be scalable, and powder morphologies can be made to order. We have also manufactured 100 large-size cylindrical lithium-ion batteries (type 18650) using LiCoO₂ produced by our industry partner – Sopo Battery Energy Co., Ltd. The electrochemical performance of those batteries has been fully evaluated via constant current charge/discharge testing. The batteries deliver an average capacity of 2200 mAh. The cycle life of the batteries has been tested as 500 cycles while maintaining 80% of the initial capacity. These “type 18650” lithium-ion batteries can be used to power electric bicycles.

In 2006 our staff remained proactive in their research and career development. Dr. A. V. Pan and Dr. G. X. Wang have received appointments by the Faculty of Engineering for Lecturer and Senior Lecturer positions, respectively. Dr. Z. P. Guo and Dr. K. Konstantinov have also been appointed to Lecturer positions at ISEM. Prof. C. Zhang, Prof. R. A. Lewis, and Dr. R. E. M. Vickers have continued to be the key personnel in maintaining and improving our terahertz facilities. We have been very active in receiving visitors from various countries and organizations. By sharing information and knowledge on numerous aspects of research we continue to increase the number of international links, collaborative activities, new research ideas, etc. More than twenty internationally renowned researchers visited our group in the year 2006. Our visiting fellows, such as D. dos
Santos from UNESP Sao Paolo State University (Brazil), have made a tremendous effort in improving the wet chemistry synthesis processes for high temperature superconductors. Prof. V. M. Pan from the Institute for Metal Physics (Kiev, Ukraine), Prof. E. W. Collings from Ohio State University (USA), Dr. H. Kimura from the National Institute for Materials Science (Tsukuba, Japan), Prof. P. Notten from Philips Research Laboratories (Eindhoven, The Netherlands), and many others gave a number of interesting and exciting talks on subjects as varied as new generation telecommunication applications, superconductivity, hydrogen storage, batteries, etc. We are grateful to these researchers for sharing their knowledge and experience with our staff and students.

Yet again we have been very successful in the ARC grant bids in the 2006 round with a total of $2,449,776 awarded. This includes a battery program in the ARC Centre for Electromaterials Sciences (H. K. Liu), three Discovery Projects (S. X. Dou/C. Jiang; Z. P. Guo/H. K. Liu; G. X. Wang/C. Zhang/K. Konstantinov/J. Z. Wang), one Linkage Infrastructure Project (S. X. Dou et al.), two Linkage Projects (Z. P. Guo; G. X. Wang) and one International Linkage Project (R. A. Lewis/R. Mendis).

All our postgraduate students worked hard on their projects and achieved many significant results. Five of our postgraduate students have completed their studies and successfully graduated. Y. Chen took a position of CEO of DLG Battery Ltd. (Shanghai, China), S. Bewlay became a patent examiner at the Australian Patent Office (Canberra), and one of our best postgraduate students, Wai Kong Yeoh, works now as a casual researcher at ISEM and will be going to Cambridge University in the United Kingdom in the middle of 2007. He has been awarded with Student Excellence Award for 2006, which he shared with another of our postgraduate student, See How Ng, who in the middle of 2007 will be joining Paul Scherrer Institute (Switzerland) as a Research Fellow. Rashmi Nigam has been very successful in her PhD program and received the Student Merit Award, while Germanas Peleckis has been awarded the Best Paper Award for two publications in Applied Physics Letters on the subject of spintronic materials. We congratulate S. Pysarenko for winning 3rd prize in poster competition at the Australian Institute of Physics Industry Day. During the same event S. Pysarenko and O. Shcherbakova received awards for Postgraduate Excellence. As usual, we have a few new postgraduate students joining our group. We welcome them and wish them all the best in their scientific endeavours.

We have further improved our infrastructure in 2006. A cryogen-free 14 T Physical Properties Measurement System will be installed at the new campus by early 2007. A number of facilities obtained via the POOL II scheme, including a Profilometer, an Electrochemistry Workstation, a Spin-Coater and a Dip-Coater, have been in operation for more than half a year. An Ultra-High Vacuum Pulsed Laser Deposition chamber is also available, thanks to tremendous effort and dedication from one of our staff researchers, Dr. Yue Zhao. He has spent an enormous amount of time adjusting and assembling this facility, sacrificing his own project constraints and timeframes. We would like to express our gratitude to Dr. Yue Zhao’s effort to make ISEM a better place. In addition, ISEM and IPRI (S. X. Dou/G. G. Wallace) have jointly succeeded in obtaining a grant of $1,500,000 supported through National Cooperative Research Infrastructure Scheme of DEST, which will significantly enhance the technical support of our extensive infrastructure. A part of this will be used to update the EBE system and surface analysis chamber.

In the area of technology transfer, UoW has signed the largest IP license agreement ever with Hyper Tech Research Inc, Ohio, USA, on commercialization of nano-SiC doped MgB2. The patent on this has entered the international patent stage. New provisional patents on carbohydrate and polymer doping into MgB2 have been filed for IP protection.

We see our future in bright colours. We have identified various goals and tasks that have to be completed in order to make our institute a world-class materials research establishment. These are world-class research facilities, a first class research team, and, most importantly, the ability to commercialize our research outcomes. We have made the first few steps toward commercialization of our research outcomes by filing a provisional patent based on advances made in the field of magnesium diboride superconductors. This, in fact, is an important step towards fulfilling the requirements under the new funding scheme — the Research Quality Framework, which concentrates on the group’s capability to actually have a positive influence on the wealth and prosperity of Australia.

S. X. DOU
Director
Management 2006

Management Committee

Chairperson: Prof. M. Sheil
Deputy Vice Chancellor, UoW
Prof. S. X. Dou
Director, ISEM
Prof. C. Cook
Dean, Faculty of Engineering, UoW
Prof. C. Zhang
Associate Director, ISEM
Prof. H. K. Liu
Research Co-Coordinator, ISEM

Industry Advisory Group

Mr. B. Buchtmann Advanced Syst. Engineer Email Limited
Dr. X. F. Gao General Manager Lexel Batteries Co. Ltd, Shenzhen, PR China
Mr. R. Neale Managing Director Alphatech International Ltd
Mr. M. Tomsic Managing Director Hyper Tech Research Ltd, Ohio, USA,
Mr. J. F. Wu Marketing Manager DLG Battery Co Ltd, Shenzhen, P.R. China
Dr. S. Zhong Managing Director Guangzhou Delong Energy Technology, Guangzhou P.R. China
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Prof. S. X. Dou, Dip., PhD, DSc, FTSE

**Associate Director**
Prof. C. Zhang, GradDipl, PhD, MA, MPhil, FAIP

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Dr. J. Horvat, BSc, PhD
Assoc. Prof. X. L. Wang, BSc, MSc, PhD, ARC QE-II Fellow
Dr. G. X. Wang, BSc, MSC and PhD
Dr. K. Konstantinov, BSc, MSc, PhD
Dr. A. V. Pan, MSc, PhD, ARC postdoctoral Fellow

**ARC Fellows**
Prof. J. H. Ahn, Assoc. Professorial Fellow
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Dr. Z. P. Guo, BSc, MSc, PhD, Australian Professorial Fellow
Prof. H. K. Liu, Dipl. For PGS, Dipl. AQC, Australian Professorial Fellow
Dr. A. V. Pan, MSc, PhD, ARC Postdoctoral Fellow
Dr G. X. Wang, BSc, MSc, PhD, ARC QE-II Fellow
Dr. J. Wang, BSc, MSc, PhD, ARC Postdoctoral Fellow
Assoc. Prof. X. L. Wang, BSc, MSc, PhD, ARC QE-II Fellow
Dr. S. H. Zhou, BSc, MSc, PhD, ARC Postdoctoral Fellow
Prof. J. M. Yoo, BSc, MSc, PhD, ARC International Professorial Fellow
Dr. D. Q. Shi, BSc, MSc, PhD
ARC Postdoctoral Fellow (Industry)

**Research Staff**
Dr. Z. X. Cheng, BSc, MSc, PhD
Dr. F. Gao, BSc, PhD
Dr. M. J. Qin, BSc, MSc, PhD
Dr. T. M. Silver, BSc, PhD
Dr. D. H. Wilke, BSc, PhD
Dr. J. H. Kim, BSc, PhD
Dr. R. Zeng, BSc, MSc, PhD
Dr. R. Mendis, BSc, PhD
Dr. S. Shrestha
Dr. P. Lyu, BSc, PhD
Dr. G. Alvarez

**Academic Staff**
Prof. C. Cook, BSc, PhD, FIEAust
Prof. D. Dunne, BSc, PhD, FIEAust
Dr. C. Freeth, MSc, PhD, MAIP
Prof. R. A. Lewis, BSc (Hons), PhD, FAIP, FRMS
Dr. A. D. Martin, MSc, PhD, MAIP
Assoc. Prof. R. E. M. Vickers, MSc, PhD, MAIP
Prof. P. Fisher, BSc, PhD

**Visiting Staff**
Prof. E. W. Collings, Ohio State University
Dr. S. Kennedy, ANSTO
Dr. S. Zhong, Delong Energy Technology, China
Prof. J. Chen, Nankai University, PR China
Prof. S. Y. Ding, Nanjing University

**Technical Staff**
Mr. R. Kinnell

**Administration Officers**
Julie Curcio
Joy de Mestre
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<tr>
<th>PhD</th>
<th>Thesis Title</th>
<th>Supervisors</th>
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<tr>
<td>Y. Chen</td>
<td>Investigation of Cathode Materials for Li-ion Batteries</td>
<td>H. K. Liu, G. X. Wang</td>
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<td>S. Y. Chew</td>
<td>Li-ion Rechargeable Batteries</td>
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<td>M. Farhoudi</td>
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<td>High-efficiency Terahertz Emitters</td>
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<td>P. Lavers</td>
<td>Electronic Structure of Perovskites</td>
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<td>Numerical Analysis of Electromagnetic Behaviour of High Tc Superconductors in Magnetic Field</td>
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<td>S. A. Needham</td>
<td>Anode and Cathode Materials for Lithium Ion Batteries</td>
<td>G. X. Wang, H. K. Liu</td>
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<td>S. H. Ng</td>
<td>Nano-structured Materials for Electrode in Rechargeable Li-ion Battery</td>
<td>H. K. Liu, J. Z. Wang</td>
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<td>M. O'Dwyer</td>
<td>Thermionic Cooling and Power Generation</td>
<td>C. Zhang, R. A. Lewis</td>
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<td>J. Park</td>
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<td>M. S. Park</td>
<td>Thin-film Microbatteries and Semiconductor Nanowires</td>
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<td>S. H. Pilehrood</td>
<td>Electronic Properties of Semiconductor Nanostructures under Intense Terahertz Radiation</td>
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<td>Critical Current Density and Flux Pinning in HTS</td>
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<td>A. Shcherbakov</td>
<td>Thermal Stabilization of MgB₂ Wires</td>
<td>S. X. Dou, J. Horvat</td>
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<td>D. Chen</td>
<td>Novel Spintronic Materials</td>
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<td>O. Shcherbakova</td>
<td>The Effect of Nano-scale SiC Doping on the Superconducting Properties of MgB₂</td>
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<td>M. Smith</td>
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<td>B. Winton</td>
<td>An Investigation of the Surfaces of Biomaterials</td>
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<td>Study of precursor materials for MgB₂ Superconductors</td>
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<td>Control of Nanostructure for Enhancing Superconductor Performance through Chemical Doping</td>
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<td>L. Yuan</td>
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<td>H. K. Liu, K. Konstantinov, G. X Wang</td>
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<td>Effect of Processing Atmosphere in MgB₂</td>
<td>S. X. Dou, A. V. Pan</td>
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<td>Y. Zhao</td>
<td>Fabrication and Characterization of MgB₂ Films</td>
<td>S. X. Dou, M. Ionescu</td>
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<td>R. Nigam</td>
<td>Study of Coexistence of Superconductivity and Magnetism</td>
<td>A. V. Pan, S. X. Dou</td>
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<td>K. de Silva</td>
<td>Diamond Growth</td>
<td>S. X. Dou, A. V. Pan</td>
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<td>S. X. Dou, Y. Zhao</td>
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## Completions

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<th>When Awarded</th>
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<tr>
<td>M. Apperley</td>
<td>1992</td>
<td>Chief Technologist</td>
<td>1993</td>
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<tr>
<td>The Fabrication of High Tc Superconductor Wire</td>
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<td>Australian Superconductors</td>
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<td></td>
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<td>Business development manager</td>
<td>2004</td>
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<tr>
<td></td>
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<td>University of Sydney</td>
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<tr>
<td>R. Baker</td>
<td>2001</td>
<td>Professional Officer</td>
<td>2003</td>
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<tr>
<td>Zeeman and Piezo-spectroscopy of Antimony and Aluminium in Germanium</td>
<td></td>
<td>University of Wollongong</td>
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<td>S. Bewlay</td>
<td>2006</td>
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<td>Investigation on Li-Co-Ni System for Lithium Ion Batteries</td>
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<td>Canberra</td>
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<td>A. Bourdillion</td>
<td>1992</td>
<td>Senior Engineer</td>
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<tr>
<td>Microstructure, Phase Characterization and Texture of HTS</td>
<td></td>
<td>Hewlett Packard, Singapore</td>
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<td>J. P. Chelliah</td>
<td>2000</td>
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<td>Optical Spectroscopy of Semiconductors</td>
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<td>DLG Battery Shanghai CO.LTD</td>
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<tr>
<td>J. Chen</td>
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<td>High Energy Storage Material for Rechargeable Nickel-Metal Hydride Batteries</td>
<td></td>
<td>Osaka National Research Institute</td>
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<td>M. Ionescu</td>
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<td>Growth and Characterization of Bi-2212 Crystals and Improvement of Bi-2212/Ag Superconducting Tapes</td>
<td>Assistant Director</td>
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<td>Optical &amp; Electrical Studies of Resonant Tunnelling Heterostructure</td>
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<td>A Study of the Fabrication and Characterization of High Temperature Superconductor YBa2Cu3O7 Thin Films</td>
<td>Associate Research Fellow</td>
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<td>Data Analysis and Anode Materials for Lithium Ion Batteries</td>
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<td>The Fundamental Mechanisms Involved in the Production of Thin Films by Pulsed Laser</td>
<td>Teacher</td>
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<td>D. Marinaro</td>
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<td>A Study into the Effects of Fission-Fragment Damage on Activation Energies in Ag/Bi2223 Tapes</td>
<td>Scientist</td>
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<td>D. Milliken</td>
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<td>Uranium Doping of Silver Sheathed Bismuth-Strontium-Calcium-Copper-Oxide Superconducting Tapes for Increased Critical Current Density through Enhanced Flux Pinning</td>
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<td>Near Band-edge Optical Properties of MBE GaAs and Related Layered Structures</td>
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<td>Development of Superconducting Magnesium Diboride Conductors</td>
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<td>Processing and Characterization of Superconducting Ag/BiPbSrCaO Composite</td>
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<td>Thermodynamic and Dielectric Properties in Modulated Two-Dimensional Electronic Systems</td>
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<td>Amorphous and Nanocrystalline Hydrogen Storage Alloy Materials for Nickel-Metal Hydride Batteries</td>
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<td>Spectroscopy of the Effect of Strains and Magnetic Field on Shallow Acceptor Levels in Germanium</td>
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<td>Magnetic Hysteresis and Relaxation in Bi2212 Single Crystals Doped with Iron and Lead</td>
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<td>Design and Characterization Of HTS Coils</td>
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<td>Development of a Novel Plate Making Processing Technique for Manufacturing Valve-Regulated Lead-Acid Batteries</td>
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<td>A. Warner A Spectroscopic Study of Acceptors in Germanium</td>
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<td>J. M. Xu Phase Formation and Transformation in the R-Fe-T System (R=Nd, Gd, Tb, Dy, Er, Ho, T and Lu, T=Si, Ti &amp; Zr</td>
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<td>(Bi,Pb)$_2$Sr$_2$Ca$_2$Cu$<em>3$O$</em>{10+y}$/Ag High T$_c$ Superconductors and Their Applications in an Electrical Fault Current Limiter and an Electronic High Voltage Generator</td>
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<td>S. Lee</td>
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<td>Multilayer Thermionic Cooling in GaAs-Al$<em>x$Ga$</em>{1-x}$As Heterostructures</td>
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<td>E. Sotirova</td>
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<td>Communications Assistant Star CD Pty Ltd</td>
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<td>K. Uprey</td>
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<td>J. Z. Wang</td>
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<td>Effect of Element Substitution on Superconductivity</td>
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<td>A New Method for Production and Study of Electrical Properties of Carbon Foam</td>
<td>Queensland University</td>
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<td>Z. Zhang</td>
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<td>Z. W. Zhao</td>
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<td>Nano-oxides Fabricated in-situ by Spray Pyrolysis Technique as Anode Materials for Lithium Secondary Batteries</td>
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National and International Links

The Institute has established a national and international multi-disciplinary collaborative network. This has led to information exchange, co-supervision of PhD students, joint grant proposals and joint publications with more than 40 research teams around the world. Current collaborative organizations are listed below:

**Australia**

Australian Nuclear Science & Technology Organization

Australian National University
University of Sydney
Macquarie University
University of Technology, Sydney
Monash University
University of Melbourne
University of New South Wales

University of Queensland

**International**

Atomic Institute of Austrian Universities, Vienna, Austria
Brookhaven National Lab, USA
Dalhousie University, Canada
Houston University, USA
Institute for Metal Physics, Kiev, Ukraine
Los Alamos National Lab, USA
Ludwig Boltzmann Institut für Festkörperphysik, University of Vienna, Austria.
Max-Planck Institute for Solid State Physics, Germany
Nankai University, PRC
Nanjing University, PRC
National Andong University, S. Korea
Northeastern University, Shenyang, PRC
Lund University, Sweden
Shanghai University
Tienjun University, PRC
Rensselaer Polytechnic Institute, USA
Ohio State University, Columbus, OH, USA
University of Cambridge, UK
University of Auckland, New Zealand
University of Cincinnati, USA
University of Wisconsin, USA
University of Zagreb, Zagreb, Croatia
Yamagata University, Japan
Kyushu Institute of Technology, Japan
Institute of Physics, Chinese Academy, PRC
University of Geneva, Switzerland
Korean Institute of Machinary and Materials
Imperial College, UK
Philips Research Laboratories and
Technical University Eindhoven, The Netherlands

Dr. S. Kennedy, Dr. M. James,
Dr M. Reinhard
Dr. W. Xu
Dr. S. Ringer, Dr. R. K. Zheng
A/Prof. E. Goldys
Prof. J. G. Zhu, G. Smith
Dr. Y. B. Cheng, Dr. Krishnamurthy
Prof. D. Jamieson
Dr. R. Ramer, Prof. M. S. Kazakos,
Prof. P. Munroe, Prof. S. Li, Prof S. Campbell
Prof. G. Q. M. Lu

Prof. H.W. Weber
Dr. X. Q. Yang, Dr. Y. M. Zhu
Prof. J. Dahn
Prof. R. Weinstein
Prof. V. Pan
Dr. A. Serquis, Dr. Q. X. Jia, Dr. X. Z. Liao

Prof. U. Habermeier, Dr. C. T. Lin
Prof. J. Chen, Prof. Y. H. Tang
Prof. S. Y. Ding, Prof. W. M. Chen
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Prof. D. Shi
Prof. D. Larbalestier, Dr. A. Polyanskii
Prof. E. Babic, I. Kusevic
Dr. S. Kambe, Prof. Olishima
Prof. T. Masushita
Prof H. H. Wen
Prof. R. Flukiger
Prof. J. M. Yoo
Dr. L. Cohen,

Prof. Dr P. H. L. Notten
1. Progress Report on ARC Centre of Excellence Research

**Develop highly conductive nanocomposite electrodes for Li-battery** *(within the ARC Centre of Excellence for Nanostructured Electromaterials, Director: G. G. Wallace)*

**Funded:** 07/2005 2006 2007 2008 2009 07/2010

**Project ID:** CE0561616

**Chief Investigator:** H. K. Liu


**PhD students:** S. H. Ng, M. S. Park, S. Y. Chew

**Progress made in 2006**

**Carbon-coated silicon nanocomposites:** were produced by spray pyrolysis in air with citric acid as the novel carbon source. The spray pyrolysis method used in this study is instantaneous, versatile, inexpensive, industrially oriented, and can be operated over a large temperature range (150-1400 °C). Carbon-coated Si nanocomposites can reversibly store lithium with both a high capacity of 1489 mAh/g and a high coulombic efficiency above 99.5%, even after 20 cycles.

**Spray Pyrolyzed PbO-Carbon Nanocomposites as Anode for Lithium-Ion Batteries:** A new approach has been used to prepare nanostructured lead oxide-carbon (PbO-C) composites via the spray pyrolysis technique. The prepared powders consist of fine nanocrystalline PbO homogeneously distributed within an amorphous carbon matrix with highly developed surface area. The combination of spray technology and carbon addition increased the specific surface area and the conductivity of PbO, improved the specific capacity, and maintained cycle life with a reversible capacity more than 100 mAh/g after 50 cycles.

**Co$_3$O$_4$–C composite as anode materials in Li-ion batteries:** Co$_3$O$_4$–C composite powder has been synthesized via spray pyrolysis of cobalt nitrate-sugar solution at 600°C and assessed for application as anode materials in Li-ion batteries. Charge-discharge cycling of half-cells indicates a stable reversible discharge capacity above 800 mAh/g. Equivalent circuit modelling of Nyquist plots show the Co$_3$O$_4$–C electrode has significant kinetic advantages over non-composite transition metal oxide electrodes.

**Lithium-ion reversible and irreversible capacities of Si–DC nanocomposites:** were estimated from charging/discharging tests. A large irreversible capacity and a large hysteresis between charging and discharging curves can be observed from the typical charging/discharging curves of the Si–DC nanocomposites, which is typical for silicon-based electrodes. It is found that the electrochemical performance of the Si–DC nanocomposites is significantly influenced by the pyrolysis conditions of the sample production. The sintering temperature, the heating rate, the argon flow rate and the morphology of the PVA all affect the final products.

**Electrochemical properties of Si thin film prepared by pulsed laser deposition for lithium ion micro-batteries:** Si thin films were deposited directly on stainless steel substrates that act as current collectors using the pulsed laser deposition (PLD) technique. Amorphous Si films of different thicknesses were obtained at the Ar gas pressure of 5×10$^{-5}$ Torr and a temperature of 500 °C but different deposition times. The anodic electrochemical performance of the films was examined in the range of 0.005–1.5V, which revealed excellent cyclic stability without any large capacity fade up to the 70th cycle.

**Mesoporous Au film as anode material for Li-ion battery:** Mesoporous gold sponges were prepared by chemical removal of Al from thin films of an AuAl$_3$ precursor that had been deposited on Cu sheet. A multilayer mesoporous Au film showed superior characteristics compared to an ordinary Au film, with a higher specific charge passed. Capacity of all tested electrodes was in the vicinity of 500 mAh/g during the initial discharge cycle, but was subject to a steep fade during subsequent cycles. The capacity of the multilayer, mesoporous gold settled at about 80 mAh/g after 30 cycles, while that of the ordinary Au film fell to about 10 mAh/g.

**Publications:**


* IF = Impact Factor
2. Progress Reports on ARC Large/Discovery Projects

First principles for development of high temperature superconducting wires

Funded: 2002 2003 2004 2005 2006
Project ID: DP0211240
Chief Investigators: S. X. Dou, J. Horvat
Postgrad Students: S. Keshavarzi, M. Roussel

The objective of the proposed project: is to provide new insights into fundamental HTS material properties such as critical current density, flux pinning, flux dynamics and AC losses by focusing on the complex interplay between physics, fabrication and materials issues.

Improving critical current in MgB₂ by nano-carbon substitution: The effects of nano-carbon doping on superconducting properties of MgB₂ were studied. Measurements show that the best critical current density (J_c) is obtained at high sintering temperatures (over 900 °C). Values of J_c in high field approaching those for nano-SiC doping were obtained for the highest sintering temperatures.

Mechanisms enhancing superconducting properties of MgB₂ with nano-SiC doping: Nano-SiC doping of MgB₂ results in the best critical current, however, the exact mechanisms were so far unclear. This work has revealed the mechanisms and showed why nano-SiC doping gives better results than nano-C doping. It was shown that carbon gets released from nano-SiC at around 600 °C, when Mg powder reacts with SiC, producing Mg₂Si. At the same time, MgB₂ is formed. This newly formed carbon is highly chemically active, and it will occupy some of the boron sites in MgB₂ crystals. This introduces vortex pinning in MgB₂. An important element of nano-SiC doping is that the best J_c is obtained at sintering temperatures of about 600 °C. This is in contrast to the pure carbon doping, where best J_c and highest carbon doping level are obtained at higher temperatures (over 900 °C). J_c for pure carbon doping and sintering at high temperatures is nevertheless smaller than for nano-SiC doping and sintering at low temperatures. This occurs because, in addition to the vortex pinning induced by carbon substitution for boron, there are pinning centres due to grain boundary defects. As a result of low-temperature sintering with nano-SiC doping, small crystal grains and high concentration of surface pinning centres is formed. However, grain size for high-temperature sintering results in large grain size and smaller density of surface pinning centres. This is the main reason for nano-SiC doping giving better critical current than carbon doping, because it provides benefits in two ways: pinning due to the boron substitution for carbon and pinning due to the surface defects.

Pinning by twin planes in Sm-123 superconductor: Vortex pinning by twin planes in Sm-123 superconductor leads to an appearance of a peak effect in the field dependence of J_c, which enhances the value of J_c at high fields. Magnetic hysteresis loops of this material, measured at different angle φ to the twin planes, collapse into two distinct families. For φ<6°, there is a peak effect, whereas for φ>6° there is no peak effect. This proved to be a very reliable method for distinguishing the pinning effects of twin planes from those of other pinning centres.

Nd-123 multilayered films: High quality NdBa₂Cu₃O₇−δ/PrBa₂Cu₃O₇−δ/NdBa₂Cu₃O₇−δ films were grown by the pulsed laser deposition technique. Measurement of tunnelling conductance proved to be a powerful technique for measuring spin states in this film.

Non-linear dynamics in electronic systems and devices under intense terahertz radiation

Funded: 2004 2005 2006
Project ID: DP0452713
Postgraduate student: M. Smith

Project summary: Non-linear interactions allow for a detailed and intricate probing of materials. Sufficiently high-power light directed at a subject can yield spectroscopic data about multiple material parameters, providing a unique diagnostic tool for many applications. We propose to study the non-linear dynamic properties of electronic systems and devices under various external conditions. A thorough understanding of non-linear properties will accelerate development of new optoelectronic devices in the terahertz frequency regime. Examples of these devices are oscillators and sensors. The main research carried out in 2006 is listed below.
a) We carried out a theoretical and computational study on the mechanism of two-colour terahertz emissions in systems with spin-orbit coupling. By developing a model based on the density response and mean-field approximation, we demonstrated that spin-orbit interaction in semiconductor quantum wells can be used to tune the intensity and frequency of two colour emitters.

b) We carried out measurements of emission spectra in InAs wafers. The angular dependence is determined.

c) We performed measurement of emission spectra of photoconductive terahertz emitters. Two photoconductive emitters were grown in the facility at the Chinese Academy of Sciences. The measurement was not complete and new samples will be made.

d) We calculated the finite frequency density response of semiconductor multilayer systems in the presence of spin-orbit coupling. The terahertz plasmon excitation spectra were determined.

Publications:


9. C. Zhang, Z. S. Ma, and W. Xu, “Frequency-dependent Hall effect in spintronic systems under zero magnetic field”, Physica E 34, 321 (2006);


Control of nano-structure for enhancing the performance of magnesium diboride superconductor by chemical doping

Funded: 2004 2005 2006
Project ID: DP0449629
Chief Investigators: S. X. Dou, M. J. Qin
Partner Investigators: D. C. Larbalestier, R. L. Flükiger, L. F. Cohen
Postgraduate Students: W. K. Yeoh, O. Shcherbakova, Y. Zhang

The aims of the proposed program are to understand the underlying mechanisms that control the Jc of MgB2 by tailoring the microstructures and defects on the nanoscale to enhance the flux pinning density via readily scalable techniques such as chemical doping.

Research activities of our project have continued very successfully with preparation and investigation of a range of MgB2 samples prepared by various methods, including solid state reaction, a liquid mixing approach, and the in-situ reaction technique under different formation environment conditions. Different chemical doping sources and methods have been adopted, and the crystal structure and microstructure variations have been studied using Rietveld refinement of x-ray diffraction patterns and scanning/transmission electron microscopy, respectively. The results are briefly outlined as follows:

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1. A detailed analysis of the effect of excess Mg indicated that the $T_c$ was decreased, and the $J_c$ and $H_{c2}$ were significantly enhanced in 10% excess samples compared to those in normal samples. Microstructure analysis indicated that the MgO content was significantly reduced in the 10% excess Mg samples, which may be because the 10% excess Mg changed the formation environment conditions for MgB$_2$, with more oxygen in the Mg(BO) phase or dissolved in the MgB$_2$ matrix, and with less forming MgO, since Mg(BO) phase is an effective flux pinning center, while nano MgO in grain boundaries may act as a flux pinning center, but degrades the connectivity as well.

2. A systematic study of the effect of nano carbon-coating on boron particles indicates that there are advantages of nano carbon-coating on B particles, such as, homogeneous mixing of the carbon dopant with the B powder, avoidance of expensive nano-additives, and high reactivity of the nano-C layer on B particles, and so the $J_c$, $H_{irr}$, and $H_{c2}$ of MgB$_2$ were significantly enhanced compared to uncoated samples. Moreover, a systematic study of MgB$_{2-x}$C$_x$ implied that the samples doped with $x = 0.2$ sucrose have optimized current density at high magnetic field with the optimized sintering temperature for high current density 850 °C, so $H_{c2}$ and $H_{irr}$ can be improved due to the sucrose doping.

3. A systematic study of the effect of polymer addition using B powders of different purity (92% B and 99% B) implies that Polyvinyl alcohol [-C$_2$H$_4$O-]$_n$ (PVA) as a representative polymer can be used as an additive to MgB$_2$. The polymer can be oxygen (O) free or have a low O content (C:O = 2:1), which reduces the impurities in MgB$_2$ that result from doping. The PVA decomposes at the same temperature as MgB$_2$ formation, and provides highly reactive C to homogeneously substitute for B at low temperature. PVA doping enhances both the connectivity and flux pinning, and the $J_c$ of the PVA doped samples was improved over the whole field range.

4. In contrary to the previous results for pure MgB$_2$ samples where the temperature dependence of Bsb(T) can be understood using a model of randomly distributed weak pinning centers via the spatial fluctuations of the transition temperature (δ$T_c$ pinning), in our substituted samples the pinning can be attributed to the mean-free-path fluctuations (δl pinning). We assumed that the C-substitution in MgB$_2$ leads to variations in the charge-carrier mean free path l near lattice defects in the substituted samples.

**Hydrogen storage materials for energy conversion applications**

**Funded:** 2004 2005 2006  
**Project ID:** DP0449660  
**Chief Investigators:** H. K. Liu, Z. P. Guo (APD)  
**Partner Investigators:** J. Lee, A. Zuettel, P. H. Notten

**MgH$_2$-carbon composites:** we can conclude that different ball-milling modes lead to dissimilar amounts of hydrogen trapped by boron and graphite. High-energy impact mode is in favour of trapping hydrogen atoms. The interaction between boron and hydrogen also depends on the milling mode applied, with the low-energy mode resulting in a higher percentage of strong B-H bonds, in contrast to the higher percentage of weak B-H bonds in high-energy milled boron. As for graphite, the formation of hydrogenated carbon clusters also depends on the milling mode applied, with the sample obtained through the high-energy mode consisting of a variety of carbon clusters, in contrast to only two existing in the sample obtained through the low-energy mode. The exothermic-like peaks existing in graphite products and boron through impact mode actually are a combination of one small endothermic peak and one large exothermic one, which is assumed to be due to hydrogen desorption and subsequent re-arrangement of carbon/boron atoms. Only endothermic peaks are visible for boron product through shearing mode.

**MgH$_2$ and iron oxide composites:** the composites were synthesized through a low-energy shearing mode ball mill. The particle sizes of the as-prepared composites are very small, around 300 nm for MgH$_2$ + Fe$_2$O$_3$ and 400 nm for MgH$_2$ + Fe$_3$O$_4$. There is a little difference in the decomposition temperature between the two as-prepared samples. During hydrogen desorption, both Fe$_2$O$_3$ and Fe$_3$O$_4$ were reduced by magnesium, with elemental Fe existing in the dehydrogenated composites. There is a little difference in the decomposition temperature of the rehydrogenated composites, which can be attributed to the reduction of iron oxides during hydrogen desorption. The more capacity degradation of rehydrogenated MgH$_2$ + Fe$_2$O$_3$ composite is also a result of the reduction reaction, during which more magnesium was consumed than that consumed by the same amount of Fe$_3$O$_4$.

**Spherical clusters of metal-oxide nanorods:** NiO doped or co-doped with different elements (such as Zn, Co, Mn, etc.) and at different doping levels were prepared by chemical precipitation and thermal decomposition. It was found that the doping elements and doping level can change the length and the diameter of the nanorods
under the same preparation conditions, but the spherical clusters were observed in all the doped NiO samples (Zn,Co)-doped NiO with the atomic ratio of the nickel, zinc, and cobalt at 92.4 : 2.1 : 5.5. Hydrogen adsorption/desorption on doped NiO materials with different surface areas has been investigated. The hydrogen storage capacity is mainly governed by the surface area.

**Development of high-temperature superconducting coated conductors by pulsed-laser deposition technique for future long-length applications**

Funded: 2004 2005 2006  
Project ID: DP0451267  
Chief Investigators: A. V. Pan (APD), M. Ionescu

Much denser YBa$_2$Cu$_3$O$_y$ (YBCO) superconducting films at least 1μm thick with smooth surfaces have been obtained after introducing (Y/Nd)BCO multilayered structures. A significant enhancement of current carrying abilities has been achieved in these pulsed laser deposited films. $J_c$ has been increased by a factor of up to three in the entire field range. The imitation of the (Y/Nd)BCO multilayered structure by using YBCO “interlayers” has also exhibited a considerable improvement in the current carrying ability. Similarities and differences between these two “multilayering” approaches, leading to the observed effects, are discussed. The presence of interfaces even without element variation is likely to be the key to the improvements observed. In order to further promote $J_c$ enhancement, small “multilayered” additions of silver (Ag) to the films and multilayers provide various results: (i) rather strong enhancement for rather thin films and low addition levels, (ii) considerable degradation for large addition levels, and (iii) much less pronounced effect for thicker films. The enhancement of $J_c$ is observed in zero and low magnetic fields, but has almost no effect at higher fields. These experimental observations are discussed in terms of pinning, transparency and structural modifications introduced during the deposition of the film structures. The study of local flux distribution in YBCO thin films via the magneto-optical (MO) technique shows that surface roughness and microstructure, as well as the size and nature of inhomogeneities influence the flux penetration behaviour. In addition, the MO technique gives new insight on the high critical current density multilayer YBCO thin films.

Rows of growth-induced out-of-plane edge dislocations forming low-angle boundaries (LAB) are shown to play a key role in achievement of the highest $J_c$. The developed model takes into account the transparency of LAB’s for supercurrent as well as the pinning of vortex lattice on a network of LAB’s. This is the first model which allows to quantitatively describe $J_c(B_z)$ behaviour in the entire field range. Principal statistical parameters of the film defect structure, such as the domain size distribution and mean misorientation angle, can be extracted from $J_c(B_z)$ curves and from x-ray diffraction data. An evolution of angular dependences of $J_c$ is also consistent with the model supposing dominant pinning on edge dislocations. Strongly pinned vortices parallel to the c-axis appear to exist in tilted low magnetic fields up to a characteristic threshold field, below which the magnetic induction within the film obeys a simple relation $B = B_0 \cos \theta$, which explains the absence of the $J_c(\theta)$ maximum in low fields. The peak and a hysteresis of $J_c(\theta)$ observed in an intermediate-field range are discussed in terms of film thickness, surface quality, and orientation of the applied field. The observed effects are also consistent with our model.

Different types of superconductors have been investigated at low magnetic fields and their behaviours compared. It has been shown that the temperature dependence of the $J_c(B_z)$ degradation onset can be attributed either to the temperature dependence of the magnetic penetration depth for Nb-film and MgB$_2$ bulk superconductors, or to thermally activated processes for Bi-based superconductors and YBa$_2$Cu$_3$O$_y$ superconducting films. In both cases the vortex pinning influence appears to have a secondary role, affecting the effective vortex depinning radius.

**Publications:**

4. V. Pan, *et al.*, *Phys. Rev. B* 73, 052508 (2006); (IF>3)

* IF = Impact Factor
ZnSe semiconductor nanowires were synthesized by thermal evaporation of ZnSe crystalline powders under the vacuum of 10^{-3} Torr. ZnSe nanowires have diameters in the range of 30 – 100 nm, extending a few micrometers in length. The crystal structure of ZnSe nanowires was characterised by TEM and HRTEM analysis. The optical properties of ZnSe nanowires were measured via Raman and UV-vis spectroscopy.

Semiconductor SnO\textsubscript{2} nanowires were synthesized by the self-catalysis-grown technique. We found that this technique is appropriate for preparing large quantity and high quality SnO\textsubscript{2} nanowires. Since Sn has a low melting point of 231 °C, Sn particles in the starting materials form liquid nuclei on the Si substrate at the initial stage of the evaporation above 300 °C, then leading to the vapour-liquid-solid (VLS) growth of the SnO\textsubscript{2} nanowires at 900 °C. High-resolution TEM (HRTEM) imaging and selected area electron diffraction (SAED) determined that SnO\textsubscript{2} nanowires grow along [100] direction with an interplanar spacing of approximately 0.47 nm between neighbouring [100] plane of tetragonal SnO\textsubscript{2}. Through the measurement of Raman spectra of SnO\textsubscript{2} powders and SnO\textsubscript{2} nanowires, we found the downward shift of the B\textsubscript{2g} vibration mode at 777 cm\textsuperscript{-1}, which could be caused by the size effect of nanowire structure. We tested lithium storage capacity of the as-prepared SnO\textsubscript{2} nanowires. The SnO\textsubscript{2} nanowires show much higher Li\textsuperscript{+} storage and relatively smaller initial irreversible capacity of 1134 mAh/g under the galvanostatic charge/discharge. In addition, the SnO\textsubscript{2} nanowires exhibited notably higher initial coulombic efficiency (46.9\%) than that of the SnO\textsubscript{2} powders (31.0\%). The improved performance of SnO\textsubscript{2} nanowires could be possibly attributed to more reaction sites and enhanced charge transfer on the surface of SnO\textsubscript{2} nanowires because the 1D nanowire structure has a large surface area and high length/diameter ratio.

In\textsubscript{2}O\textsubscript{3} semiconductor nanowires were synthesized efficiently by chemical vapour deposition method through carbon thermal reduction. The diameter, length and morphologies of In\textsubscript{2}O\textsubscript{3} nanowires can be varied by controlling the synthetic conditions. The In\textsubscript{2}O\textsubscript{3} nanowires were characterised by HRTEM, Raman spectroscopy and photoluminescence spectroscopy. In\textsubscript{2}O\textsubscript{3} nanowires show similar photoluminescence spectra as that of crystalline In\textsubscript{2}O\textsubscript{3} powders, indicating the perfect crystal structure of nanowires. The application of In\textsubscript{2}O\textsubscript{3} nanowires for gas sensors was tested.

Publications:


2. M. S. Park, G. X. Wang, Y. M. Kang, D. Wexler, S. X. Dou, and H. K. Liu, “Preparation and electrochemical properties of SnO\textsubscript{2} nanowires for application in Lithium-ion batteries”, \textit{Angew. Chem. Int. Ed.} 46, 750 (2007);


Exploration for new materials for spintronics

Major achievements in 2006 are:

1) We have proposed a novel idea to use superconducting Josephson vortices to manipulate the spin of electrons for Spintronic applications. It is proposed that the Josephson vortices could be used to manipulate the spin and charge in magnetic semiconductors in the same way as SVs. Hybrid systems consisting of layered superconductors with Josephson junctions and magnetic semiconductors has been suggested.
2) We have carried out a theoretical study on the nucleation pinning and coercivity in magnetic nano-systems. The nucleation and pinning fields have been derived for an exchange-coupled hard/soft/hard magnetic nano-system within an analytical micro-magnetic approach. For the first time, the analytical results could be compared with numerical and experimental coercivity directly to differentiate the coercivity mechanism quantitatively.

3) We have further studied a series of novel transparent oxide diluted magnetic semiconductors that we have discovered by Rietveld refinement, transport, and magnetic measurements, and synchrotron radiation.

4) We have continued to study the two dimensional novel cobalt magnetic oxides using XRD, Rietveld refinement, transport and magnetic measurement and band structure calculations. High spin polarisation has been found in La doped Sr$_2$CoO$_4$ compound.

5) We have carried out a study of the growth of width-controlled MnO$_2$ nanowires from mesoporous carbon and investigation of their magnetic properties. One-dimensional α-MnO$_2$ nanowires with controlled width of 10-20 nm have been successfully fabricated. A major advantage of this approach is the efficient, fast and reproducible control of width and the facile strategy to synthesize MnO$_2$ nanowires, in addition to the high purity of the resultant material. A ferromagnetic state was found in the nano-MnO$_2$ wires.

6) We have observed very interesting experimental results of interlayer transport studies carried out on YBa$_2$Cu$_3$O$_7$/La$_{2/3}$Sr$_{1/3}$MnO$_3$/YBa$_2$Cu$_3$O$_7$ thin film multilayers. Our structures showed large magneto-resistance at high temperatures, with sharp switching between the high and low resistance states, which we assume correspond to antiparallel and parallel alignment of the moments of these hybrid structures. This work has been published in IEEE.

7) Under the support of the QEII fellowship, we have also done some research on transparent optical fibbers in collaboration with China. A fibre-optic temperature sensor based on the interference of selective higher-order modes in circular optical fibres was studied.

**Publications:**

1. X. L. Wang et al., “Josephson-vortex flow resistance in Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_y$ single crystals and its possible application in the manipulation of spin and charge textures in diluted magnetic semiconductors”, *Journal of Applied Physics*, in press;


5. X. L. Wang et al., “Band structures, and magnetic and transport properties of La doped two dimensional Sr$_2$CoO$_4$”, *Journal of Applied Physics*, accepted in Dec. 2006;


**Development of new technology for coated conductors able to carry "over-critical" current densities**

**Funded:**

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<th>Year</th>
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<th>2006</th>
<th>2007</th>
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**Project ID:** DP0557544

**Chief Investigators:** A. V. Pan, S. Zhou (APD), Y. Genenko, T. H. Johansen

The magneto-optical imaging (MOI) technique providing local magnetic flux distribution has been employed for establishing the nature of the global enhancement of the critical current density ($I_c$) in MgB$_2$ wires. The MOI has been combined with the transport current measurements to visualize the current distribution (and redistribution) influenced by the ferromagnetic sheath. The results of quantification of the supercurrent stream lines obtained did not show any local overcritical current exceeding either $I_c$, or depairing current. However, the redistribution inflicted by the soft ferromagnet indicates that the global “overcritical” current obtained is the result of the supercurrent redistribution within the superconducting core enabled by the ferromagnetic sheath.
It was determined that doping by carbohydrates, such as sugar and sucrose, by employing an innovative liquid mixing approach provides an efficient and desirable method of homogeneous, inexpensive and degradation-free mixing with host precursor materials. We have found that this approach results in atomic-scale coating of each B-particle by sugar, which enables efficient homogeneous doping in contrast to conventional sophisticated mixing of powders even with nano-scale size particles. The application of this method to MgB$_2$ leads to an enhancement of in-field $J_c$ by more than an order of magnitude. Moreover, this approach provides an additional benefit to the $J_c(B)$ performance in low fields, which does not degrade for certain doping levels. This finding opens up a new direction for manufacture of nano-scale additions using solution route. Using this newly developed method, various samples of doped MgB$_2$ wire with different pinning levels have been prepared and systematically investigated. The results show that the magnetic interaction between the ferromagnetic iron sheath and the superconducting core varies due to different flux pinning levels artificially engineered in the wires: the stronger the pinning, the more obvious the screening effect, affecting the overcritical currents. The supercurrent redistribution as a result of delayed flux entry is the central point of our exploration.

An interesting effect has been observed while experimenting with MgB$_2$ wires of various diameters and shapes. It turns out that there are possibly two contributing factors to the $J_c$ enhancement: one is the interaction between the ferromagnet and superconductor, the other is the mechanical stress inserted on the superconducting core. This is a new factor. To verify the result, a non-magnetic stainless steel sheath has been used. The different diameter of the wires affected the magnetic behaviour insignificantly at low fields, whereas the resultant $J_c$ enhancement remains unchanged.

Various designs and geometries for the combination of YBCO superconducting films and ferromagnetic iron have been attempted to achieve the global “unusual” (overcritical) $J_c$ enhancement. The influence of the ferromagnet on the superconductor is obvious and clearly changes depending on the design and geometry.

**Publications:**

**Development of novel ferroelectric magnetic materials for multi-functional applications**

**Funded:** 2006 2007 2008  
**Project ID:** DP0665873  
**Chief Investigators:** X. L. Wang, Z. X. Cheng  
**Assoc. Investigators:** T. Shrout, W. Wen, K. Yamaura, K. D. Liss, R. Piltz  

The project started on 1st July 2006 and proceeded as planned. Various new composite materials scheduled in the original proposal have been successfully made, and some of them are well characterized. The following results were obtained in the last six months:

1) A new ferroelectric thin film with the composition of Bi$_{3.25}$Sm$_{0.75}$Ti$_3$O$_{12}$ and with strong preferred orientations along the c-axis and the (117) direction was fabricated on Pt/TiO$_2$/SiO$_2$/Si substrate by pulsed-laser-ablation. Measurements on Pt/BSmT/Pt capacitors showed that the c-axis oriented film had a small remanent polarization ($2P_r$) of 5 $\mu$C/cm$^2$, while the highly (117) oriented film showed a $2P_r$ value of 54 $\mu$C/cm$^2$ at an electrical field of 268 kV/cm and a coercive field $E_c$ of 89 kV/cm. This is different from the sol-gel derived c-axis oriented Bi$_{3.15}$Sm$_{0.85}$Ti$_3$O$_{12}$ film showing a $2P_r$ value of 49 $\mu$C/cm$^2$. The highly (117) oriented film also shows fatigue resistance up to $4.5 \times 10^9$ switching cycles at a frequency of 5 kHz. This work has been published in Applied Physics Letters.
2) Ferroelectric and ferromagnetic composite films of Bi$_{3.25}$Sm$_{0.75}$Ti$_{2.98}$V$_{0.02}$O$_{12}$ (BSVT) and colossal magnetoresistive La$_{0.67}$Sr$_{0.33}$MnO$_3$ (LSMO) on Si with excellent performances of both ferroelectric and ferromagnetic properties at room temperature were successfully fabricated by pulsed laser deposition method. Saturated magnetization-magnetic field (M-H) hysteresis loops and polarization-electric field (P-E) loops proved the materials compatibilities in keeping their own intrinsic properties of LSMO and BSVT in the heterostructure. The remanent polarization ($P_r$) of the BSVT is 56 $\mu$C/cm$^2$ at an applied electrical voltage of 11V. Fatigue measurements show a 25% decrease in remanent polarization after $10^6$ read/write cycles but no further changes afterwards. This work has been published in J. Phys. D. Cond. Matter.

Publications:

1. Z. X. Cheng, X. L. Wang, K. Ozawa, and H. Kimura, “Room temperature ferroelectric-ferromagnetic Bi$_{3.25}$Sm$_{0.75}$Ti$_{2.98}$V$_{0.02}$O$_{12}$/La$_{0.67}$Sr$_{0.33}$MnO$_3$ double layer heterostructure”, J. Phys. D: Appl. Phys. 40, 703–706 (2007);


**Development of conductive buffer layers for RABiTS-based coated conductors**

**Funded:** 2006 2007 2008

**Project ID:** DP0669771

**Chief Investigators:** D. Q. Shi

We have conducted research on conductive buffer layers. The LaSrMnO system was the first choice as the conductive buffer layer. We found that La$_{1-x}$Sr$_x$MnO$_3$ (LSMO), apart from its colossal magnetoresistance (CMR) properties, is also an electrically conductive oxide with good thermal stability. For $x < 0.5$, the pseudo-cubic lattice parameter of 3.9 Å is a close match to YBCO film. However, for $x < 0.3$, the electric conductivity is better. We have studied the fabrication of La$_{0.7}$Sr$_{0.3}$MnO$_3$ buffer layer deposited by pulsed laser deposition (PLD) on single crystal SrTiO$_3$ (STO) substrate and biaxially textured Ni and Ni-alloy tapes. For the deposition on STO substrate the temperature range of epitaxial growth is larger as compared to the deposition on the Ni and Ni-alloy tapes. High quality c-axis oriented La$_{0.7}$Sr$_{0.3}$MnO$_3$ film was obtained on STO substrate, and YBCO film was deposited on the top of the buffer layer. The critical current density was $3 \times 10^6$ A/cm$^2$ at 77K and 0T, which is almost as high as on STO substrate. The deposition temperature and the atmosphere are very critical for the deposition of La$_{0.7}$Sr$_{0.3}$MnO$_3$ on the Ni and Ni-alloy tapes. Ar-4%H$_2$ can effectively prevent the formation of NiO, but the texture and surface morphology is not good if all the deposition is under this atmosphere. We deposited a thin La$_{0.7}$Sr$_{0.3}$MnO$_3$ film as a seed layer at 100 mTorr Ar-4%H$_2$, and then transferred the deposition to high vacuum, less than $10^6$ Torr. The optimal temperature is 650 °C. There is no report about this type of two stage deposition in the literature. The critical current density is about $8 \times 10^5$ A/cm$^2$ at 77K and 0T, which is comparable to the best results in the world. This work will be published in Physica C.

Another project aim relates to single buffer layers. CeO$_2$ has been widely used for buffer layers of YBCO coated conductor, however, CeO$_2$ can not be used as a single buffer layer to achieve a high Jc because it leads to cracks in the film. Yttrium stabilized zirconia (YSZ) is a good buffer layer for use as a barrier. The drawback is that it has Ba reaction with YBCO, which degrades the superconductivity. As Y$_2$O$_3$ can stabilize the high temperature ZrO$_2$ phase, CeO$_2$ also can stabilize the cubic or tetragonal ZrO$_2$ phase. Ce$_2$Y$_2$O$_7$ has a stable cubic phase, which has a lattice constant of 5.34 Å. Ce$_0.8$Zr$_0.2$O$_2$ compound is a solid solution. It was reported that for Ce$_x$Zr$_{1-x}$O$_2$ the tetragonal phase is stabilized for $0 \leq x \leq 0.16$, and both the cubic and tetragonal phases are stable for $0.16 \leq x \leq 1$. Ce$_2$Y$_2$O$_7$ and Ce$_0.8$Zr$_0.2$O$_2$ were deposited by electron-beam evaporation on biaxially textured Ni-3%W substrates as single buffer layers. It was confirmed that by controlling the deposition temperature the texture of the deposited films can also be controlled. For the Ce$_2$Y$_2$O$_7$, a pure x-axis texture can be obtained on Ni-3%W. For the Ce$_{0.8}$Zr$_{0.2}$O$_2$ there is still a small (111) peak, however, the in-plane texture is very good, even if the deposition temperature is high. XRD $\theta$ - $2\theta$ scans and f-scans were employed to examine the texture. It is suggested that biaxially textured Ce$_{0.8}$Zr$_{0.2}$O$_2$ and Ce$_2$Y$_2$O$_7$ films are good potential candidates for a single buffer layer. This is the first report about these two kinds of buffer layers, and a paper has been accepted by Physica C.
A new biaxially textured tape of Ni-0.1%Mn was used as a substrate for YBCO coated conductor through the RABiTS approach. Multi-layer optimal deposition conditions have been systematically studied (work in progress).

**High efficiency terahertz emitters**

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<td>Chief Investigators:</td>
<td>R. A. Lewis</td>
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**Funded:** 2006 2007 2008  
**Project ID:** DP0665292  
**Chief Investigators:** R. A. Lewis

**Progress made in 2006:**

**Personnel**

Stuart Hargreaves was employed as a Research Assistant for twelve weeks to set up the THz imaging system. This involved the LabView programming of the electronic interface (designed by Peter Ihnat and built by Peter Anthony) that runs the XY-mechanical raster stage (built by Andrew Scobie) that permits the acquisition of THz images using either the globar or THz laser as the source of radiation and the Golay cell as the detector of radiation. This work was finished in the twelve weeks allocated. Since then, Stuart has joined the project as a PhD student and has been involved in further refinement of the imaging system and with initial testing of the candidate photoconductive emitter materials. Daniel Pond has been employed as a Research Assistant on a casual basis over the year. He has primarily been involved in the characterization of candidate THz emitter material through purely electrical measurements. He has developed a measurement platform, based on a He cryocooler that takes IV data over a range of temperatures 300 K to 10 K using a four-terminal method, and used this to characterize many different candidate emitter materials, principally electronic oxides synthesized at UOW. Lindsey Bignell's Honours Thesis was on the subject of "Terahertz Reflectance of Polar Crystals". He measured the reflectance from a variety of candidate multilayer THz emitter materials, and by suitable analysis so determined layer thickness, doping and composition. Lindsey received First Class Honours.

**Equipment**

A large proportion of the equipment required for the project has already been purchased. This includes the lock-in amplifier and the PC to control it. State-of-the-art commercial THz emitters have been purchased from manufacturers in Lithuania and Germany. These will be used to benchmark our prototypes. Experimental THz emitters have been secured from Xian, China. Tests on the emitters from Xian have shown them all to have very low electrical resistance. The suppliers have not been surprised by this and attribute it to problems in the manufacturing and now are preparing new samples for the project. In contrast, the emitter from Lithuania has very high resistance, even under illumination. We are conducting further tests to determine the origin of this.

**Outputs**

1. Invited talk at International Conference on Optical and Optoelectronic Materials and Applications, London, July 2007: Reflectance Studies of Candidate THz emitters;
2. R. A. Lewis and S. Hargreaves, “Terahertz imaging: materials and methods”, *Journal of Materials Science: Materials in Electronics* (accepted for publication, 19 November 2006);
3. Conference presentations at the Australian Institute of Physics National Congress, Brisbane, December 2006; and at the Condensed Matter Physics Meeting, Wagga Wagga, February 2007;
4. Lindsey Bignell's Honours Thesis;

**Superconducting MgB2 thin films and structures for electronic devices and telecommunication applications**

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<td>Chief Investigator:</td>
<td>Y. Zhao, M. Ionescu, J. Du</td>
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<td>Partner Investigator:</td>
<td>E. W. Collings</td>
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30
Optimization of the in-situ off-axis PLD method by modifying the annealing temperature and annealing time. A critical temperature ($T_c$) of 34.5K was achieved by an increased annealing temperature of 700°C and a prolonged annealing time of 9 min. The surface smoothness was further improved by omitting the Mg cap-layer deposition without significant suppression of the $T_c$. It is evident that the slow, smooth growth mechanism of the off-axis deposition makes the as-grown film much stable and thus able to endure higher annealing temperatures and a longer time at elevated temperatures. Various multilayered structures with Mg$_2$Si inter-layers have also been prepared using the modified PLD technique.

Systematic microstructural studies have been carried out on the off-axis MgB$_2$ thin films. Microstructural analysis by TEM has shown a fine-grained structure. Rutherford back-scattering (RBS) results from ANSTO (conducted by Dr. M. Ionescu) show strong O incorporation in the MgB$_2$ films which is in accordance with the extent of $T_c$ suppression in different MgB$_2$ samples. An electron energy loss spectroscopy (EELS) study has been carried out on the newly achieved MgB$_2$ films in collaboration with ANU. It was found that Oxygen is concentrated in the surface layer on both Mg-capped and non-capped MgB$_2$ films. These results show that MgB$_2$ film can retain a reasonably high $T_c$ with a large amount of oxygen contamination in the film.

Microwave properties of on-axis MgB$_2$ films. Microwave properties of the MgB$_2$ films were also investigated as part of the collaboration with Dr. Tajima at Los Alamos National Laboratory, USA. The surface impedance ($R_s$) of our preliminary on-axis films has been tested. The result shows a sharp increase in $R_s$ with an increase in the peak field, which indicates that weak-links are present in the on-axis MgB$_2$ films. From our analysis, the weak-links are probably the oxygen rich grain boundaries, and this indicates that reducing the impurity level in the MgB$_2$ films is crucial for microwave performance.

Upgrade and modify deposition facilities to achieve higher performance of the MgB$_2$ films. A new ultra-high vacuum PLD deposition system has been modified for the MgB$_2$ film study. This PLD system from APX has been accomplished with 10$^{-10}$ Torr level UHV vacuum tightness, and has been equipped with a rotate able off-axis substrate stage with a radiation heater, which is capable of achieving homogeneous 2-inch large off-axis films. Another UHV RF-sputtering system from MECA2000 was tested for Mg and B deposition. Multiple problems has been identified and addressed for MgB$_2$ deposition. Both systems are expected to start to synthesize MgB$_2$ films from the first half of 2007.
3. Progress Report on SPIRT/Linkage Programs

Lithium/sulphur rechargeable battery for power applications

Funded: 2004 2005 2006
Project ID: LP0453698
Chief Investigators: H. K. Liu, J. Z. Wang (APD), G. X. Wang
Industry Partner: Guangzhou Delong Energy Technology Pty Ltd

Organic Sulphide Polybithiophene: Polybithiophene film coated stainless steel mesh electrodes, obtained by electrochemical polymerization (constant potential (CP) and constant current (CI)), has been investigated as cathode materials in the lithium/polybithiophene rechargeable battery by cyclic voltammetry, electrochemical impedance spectroscopy and long-term charge-discharge process. The effect of different growth methods on surface morphology of films and charge-discharge capacity are discussed in detail. The results show that polybithiophene-hexafluorophosphate grown by constant potential from dichloromethane (DCM) has the high stable charge-discharge performance with a discharge capacity of 81.67 mAh/g observed after 50 cycles.

Nanostructured nickel sulphide (NiS): was synthesized via a simple polyol route. The NiS powders were characterized by X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and electrochemical testing. The results revealed that the cycle life of the annealed NiS sample was improved over that of the as-prepared sample. The electrochemical performance was also tested using 1 M lithium trifluoromethanesulphonimide (LiTFSI) in a solvent of polyethylene glycol dimethyl ether (PEGDME) in order to compare with the sample tested in the conventional electrolyte of 1 M LiPF₆ in a mixture of ethylene carbonate (EC) and dimethyl carbonate (DMC). The results showed that the electrochemical properties were improved by using of the 1 M LiTFSI/ PEGDME electrolyte.

Publications:
5. A paper entitled “Nanostructured Nickel Sulphide Synthesized via a Polyol Route as a Cathode Material for the Rechargeable Lithium Battery” is under review by Electrochemistry Communication.

Novel electric field coupling technique for liquid-phase heteroepitaxial growth of carbon thin film with diamond like structure (APAI only)

Funded: 2005 2006 2007
Project ID: LP0561605
Chief Investigators: S. X. Dou, A. V. Pan
Industry Partner: Polarised Technology Pty Ltd
Masters student: K. de Silva

The aim of the project is the growth of carbon thin films with a robust diamond-like structure for high performance electronic applications via the development of a new growth technique: Electric Field Induced Coupling (EFIC), which is based on liquid-phase layer-by-layer heteroepitaxial growth.

This LP project was initially targeted to support a full time PhD student. However, we could not find a suitable PhD candidate with permanent resident status. Instead, the scholarship has been offered to a Master student for only one year.

Few innovative designs for the chamber with high electric field driven growth of the diamond-like structures has been developed, and some trials of carbon film growth in the chambers has been carried out. A direct in-situ visualisation of the growth has been incorporated. A preliminary indication of carbon-like phase presence in
between the high electric field electrodes was obtained with the help of X-ray photoemission spectroscopy at relatively modest electric fields applied. However, due to imperfection of the surfaces of the electrodes, a strong discharge is observed at higher fields. To eliminate this undesirable effect, shapes and surfaces of the electrodes have been few times re-designed and modified. The polarised optical microscopy has indicated that there were islands of the heteroepitaxial (single-crystalline like) growth. This has given us a promising sign and led us to explore the possibility of additional activation energy for the more pronounced nucleation of the heteroepitaxial growth for these films. The additional sources assessed were electrochemically driven processes of nucleation, thermal energy, direct current pulses, and irradiation with a coherent light source of high intensity. Generally, the project has led to innovative thinking not only within the scope of this research, but also in the areas such as single crystal growth and thin film deposition.

**Large-scale rechargeable lithium battery for power storage and electric vehicle applications**

**Funded:**  2004  2005  2006  
**Project ID:**     LP0453766  
**Chief Investigator:**     G. X. Wang, K. Konstantinov, H. K. Liu  
**Partner investigator:**     J. H. Ahn, B. Ammundsen  

We have carried out both extensive and intensive research on polymer electrolyte, new cathode materials, new anode materials, exploration of new materials preparation techniques, fabrication of large-size lithium-ion batteries (18650), and electrochemical evaluation of those batteries. The results and outcomes are summarised as follow.

Multi-wall carbon nanotubes (MWCNTs) were added to PEO-LiClO$_4$ solid electrolyte in order to assess their enhancement of ionic conductivity. PEO-LiClO$_4$-MWNT composites can successfully be used as solid electrolytes, provided that the additive carbon nanotubes have discontinuous forms and are homogeneously distributed within the PEO-LiClO$_4$ matrix. It was found that the addition of MWCNT can significantly enhance the ionic conductivity of the PEO-LiClO$_4$ electrolyte, mainly attributed to the enhanced amorphisation by local modification of PEO chains from crystalline to disordered arrangement. The role of inorganic ceramic fillers namely nano sized Al$_2$O$_3$ (15-25 nm) and TiO$_2$ (10-14 nm) along with ferroelectric filler SrBi$_2$Ti$_4$O$_{15}$ (SBT CIT) (0.5µm) synthesized by citrate gel technique in polymer blend electrolytes are studied and characterized. The ionic conductivity was obtained from the ac impedance spectra of the composite polymer electrolytes at 21 ºC. Enhancement in conductivity was obtained for lower wt% of the fillers with a maximum of 0.72×10$^{-5}$ S cm$^{-1}$ at 21 ºC and 1.0125×10$^{-4}$ S cm$^{-1}$ at 100 ºC for 2 wt% of SrBi$_2$Ti$_4$O$_{15}$ (SBT CIT).

Nanosize iron phosphide powders were prepared by a hydrothermal synthetic method. The products were examined by X-ray diffraction and scanning electron microscopy. The as-prepared products contain a majority of monoclinic FeP$_4$ phase with some small amounts of impurities. SEM observation shows nanosize particles of FeP$_4$ powders. The electrochemical properties of FeP$_4$ nanopowders as anode materials for lithium-ion batteries were tested via cyclic voltammetry and galvanostatic charge/discharge measurements. Cyclic voltammetry tests of FeP$_4$ electrode show the characteristic redox reaction peaks toward lithium ions. The iron phosphide anodes demonstrated an initial lithium storage capacity of 1130 mAh$^{-1}$ and a stable reversible capacity of about 700 mAh$^{-1}$. Functional metal oxide powders (LiCoO$_2$, LiFePO$_4$, SrTi$_{1-x}$Co$_x$O$_3$) have been synthesised by a novel Electric Discharge Assisted Mechanical Milling (EDAMM) processing technique. Characterisation of the as-synthesised powders by XRD, SEM, and TEM confirm near pure phases with a highly controllable morphology can be produced in only minutes. The electrochemical (LiCoO$_2$, LiFePO$_4$) and magnetic (SrTi$_{1-x}$Co$_x$O$_3$) behaviour of the powders indicates functionality that are at least matches that of powders synthesised by traditional solid-state approaches. The EDAMM technique provides significant commercial opportunities as the method has proven to be scalable and powder morphologies can be made to order. We have manufactured 100 large-size cylindrical lithium-ion batteries (18650 type) using LiCoO$_2$ produced by our industry partner – Sopo Battery Energy Co., Ltd. The electrochemical performance of those batteries has been fully evaluated via constant current charge/discharge test. The batteries deliver an average capacity of 2200 mAh. The cycle life of the batteries has been tested as 500 cycles maintaining 80% of the initial capacity. These “type 18650” lithium-ion batteries can be used to power electric bicycles.

**Publications:**

1. G. X. Wang, S. Bewlay, S. A. Needham, H. K. Liu, R. S. Liu, V. A. Drozd, J. F. Lee, and J. M. Chen, “Synthesis and characterization of LiFePO$_4$ and LiTi$_{0.01}$Fe$_{0.99}$PO$_4$ cathode materials”, *Journal of the Electrochemical Society* **153**, A25 – A31 (2006);
2. G. X. Wang, S. A. Needham, J. Yao, J. Z. Wang, R. S. Liu, and H. K. Liu, “A study on LiFePO4 and its doped derivatives as cathode materials for lithium-ion batteries”, Journal of Power Sources 159, 282 – 286 (2006);


Development of Magnesium Diboride Superconductor wires with high upper critical field for MRI applications

Funded: 2005 2006 2007
Project ID: LP0560280
Industry partners: Hyper Tech Research Inc. OH USA, Alphatech International Ltd. Sydney

The aim of the program is to demonstrate superconducting magnesium diboride (MgB2) wires with improved upper critical field (Hc2,) appropriate for large-scale applications.

Magnetic field processing to enhance critical current densities of MgB2 super-conductors: We have demonstrated that magnetic field processing results in grain refinement, homogeneity, and enhancement of Jc(H) and Hirr. The extent of improvement in Jc increases with increasing field. The Jc for a 10 T field processed CNT doped sample increases by a factor of 3 at 10 K and 8 T and at 20 K and 5 T, respectively. Hirr for the 10 T field processed CNT doped sample reached 9 T at 20 K, which exceeded the best value of SiC doped MgB2 at 20 K. Magnetic field processing reduces the resistivity in CNT doped MgB2, straightens the entangled CNTs, and improves the adherence between CNTs and the MgB2 matrix. The difference in magnetization force for various components during Mg melting improves the migration and diffusion, and is responsible for the improvement of Jc. This method can be easily scaled up for continuous production of MgB2 superconductors and related systems.

Aluminium-Stabilized Magnesium Diboride - a New Light-Weight Superconductor Wire: The processing of MgB2 wires at 600°C has been demonstrated, so all the advantages of Al stabilization can be realized. We achieved in situ powder-in-tube (PIT) “low temperature processing” of mixed Mg+B powders in an Al tube lined with a protective Fe barrier. Reaction heat treatment at 600°C for up to 3 hours led to complete MgB2 formation; furthermore, no reaction between the Fe barrier and the Al sheath took place at 600°C. The Fe/Al clad wires showed the same magnetic and electrical properties as those with an all-Fe sheath. The MgB2/Fe/Al conductor, mainly made up of low-density components, will make a tremendous difference, especially for airborne, aerospace, and other applications where weight is important.

Effect of processing temperature on flux pinning and upper critical field of nano-carbon doped MgB2 in high magnetic field: SiC and C doped MgB2 exhibit opposite trends in the dependence of Jc and Hc2 on sintering temperature. This is explained by the different reactivity of carbon available upon creation of MgB2 for the two types of doping. Nano-carbon doped MgB2 requires sintering temperatures in excess of 900°C to obtain high carbon substitution for boron, enhancing the vortex pinning and impurity scattering of charge carriers. However carbon substitution in nano-SiC doped MgB2 occurs at less than 650°C, allowing lower sintering temperature and a high degree of carbon substitution. Both pure and SiC doped MgB2 benefit from low sintering temperature, since it results in formation of more grain boundary defects. Substantial carbon substitution can compensate for the disadvantage of sintering at high temperature of nano-C doped MgB2, giving the best Jc of 4.8 x 10^3 A/cm² at 4.5 K and 12 T.

Publications:

* IF = Impact Factor
4. Progress Reports on International Linkage Award Projects

*Magneto-optical imaging of super-current flow in superconducting tapes and wires*

**Funded:** 2004 2005 2006  
**Project ID:** LX0453582  
**Chief Investigators:** S. X. Dou, A. V. Pan – University of Wollongong  
T. H. Johansen – University of Oslo

This project is aimed at establishing the connections between local and global superconducting current-carrying abilities in magnesium diboride and high temperature superconducting tapes and wires with the help of local high-resolution magneto-optical imaging.

Research exchange activities included the visits of Dr. Pan from ISEM, UoW to the University of Oslo to use the MOI facilities there, as well as Prof. Johansen visited ISEM, UoW twice and gave seminars, conducted collaborative research work, and jointly prepared ARC discovery projects.

The study of local flux distribution in YBCO thin films via the magneto-optical (MO) technique shows that surface roughness and microstructure, as well as the size and nature of inhomogeneities influence the flux penetration behaviour. In addition, the MO technique gives new insight on the high critical current density multilayer YBCO thin films. The differences in the $J_c$ values calculated from the magnetic measurements and the MO images give rise to three main issues:

(i) The $J_c$ values given by the MO images appear to be higher than the $J_c$ values calculated from the magnetization loops under the same conditions of applied field and temperature. This reproducible systematic discrepancy was found to be connected to the measurement technique and not to the sample or measurement conditions.

(ii) The $J_c$ value estimated from the local current map quantification, which we have developed during this joint project, in the multilayer film appears to be lower than in the monolayer film with the optimal thickness, which contradicted the results obtained from the magnetization measurements. The difference was explained by the presence of outgrowths on the surface of the multilayer, which could be as large as 0.6 $\mu$m high. These outgrowths increases the distance between the actual surface of the film and the MO indicator film, leading to underestimation of $J_c$.

(iii) $J_c$ estimated for the thickest films with the help of the local current density maps appeared to be the lowest, whereas the magnetic measurements give $J_c$ similar to that of the multilayer film and larger than that for the film with optimal thickness. In the case of the thickest film, the top layer exhibits numerous holes and appears to be very rough. As a result, the magnetic flux penetrates the top layer more easily, so that the calculated $J_c$ is underestimated.

Magneto-optical imaging was used to study dendritic flux penetration in films of MgB$_2$. By repeating experiments under the same external conditions, reproducible features were seen in the pattern formation; dendrites tend to nucleate from fixed locations along the edge. However, their detailed structure deeper inside the film is never reproduced. The reproducibility in nucleation sites is explained as a result of edge roughness causing field hot spots. Using magneto-optical imaging one always finds that a concave dent in the rim of a film causes the external field to focus into extraordinary high values. Such a field “hot spot” arises due to the sharp bending of the shielding current around such an edge defect. It is here the strong curvature of the current flow leads to the field amplification. At convex corners, however, the current curvature is opposite, and hence reduces the external field locally. In films showing dendritic flux penetration, it is a matter of where along the rim the external field is exceeding the threshold field value. This will then in most cases occur on sites with geometrically induced field hot spots. Since these sites obviously are fixed, it leads to a high degree of reproducibility as to exactly where along the edge dendritic structures start to grow. However, the sequence in which these sites launch a flux dendrite is much less reproduced, thus showing that fluctuations are also playing a major role in triggering the instability. It is expected that this description applies not only to the case of MgB$_2$, but for all thin films that display this instability.
Improvement of critical current density in MgB$_2$ wire and tapes and Y-Ba-Cu-O coated conductors

**Funded:**
2005 - 2006

**Project ID:**
LX0559656

**Chief Investigators:**
X. L. Wang, S. X. Dou, and J. M. Yoo

The linkage international professorial fellow (IF) and CIs have mutually visited in 2006. The following results have been achieved in the second year of this project:

We report for the first time that significant flux pinning enhancement in MgB$_2$ can be easily obtained using a liquid additive, silicone oil. MgB$_2$ bulk samples with 0 up to 30 wt% silicon oil added were prepared by an in-situ reaction. Results showed that the Si and C released from the decomposition of the silicon oil formed Mg$_2$Si and substituted into B sites, respectively. Increasing the amount of the Si oil up to 15 wt% has resulted in the reduction of the lattice parameters, as well as $T_c$ and $R(300 \text{ K})/R(T_c)$ values, accompanied by a significant enhancement of $J_c(H)$, $H_{irr}$, and $H_{c2}$.

The method of low pressure annealing was adopted to enhance the removal of HF gas from the surface of the MOD-YBCO films, hence to increase the growth rate of YBCO films. In this work, the total pressure in annealing process was varied from 700 Torr to 1 Torr and its effect on the growth of YBCO films was compared with atmospheric pressure. The lower pressure was found effective to increase the growth rate and to control the pore size of the YBCO films in MOD method. A fast growth of MOD-YBCO films was realized with high critical current density over 1 MA/cm$^2$ using low pressure annealing. Large pores, usually observed at atmospheric pressure in MOD method, disappeared and also the number of pores was reduced.

The superconducting property and microstructure of Al doped MgB$_2$ tapes were investigated with X-ray diffraction, optical microscopy and magnetic measurements. The $J_c$ value of MgB$_2$ tapes was increased with Al addition. The $J_c$-$B$ curves show enhancement in $J_c$ ($B$), which suggests that the microstructure and transport properties of MgB$_2$ tapes have been improved with Al addition.

Precursor solutions with low Fluorine content for MOD processing of YBCO coated conductors were synthesized with F-free Y & Cu precursor. The Fluorine content in the precursor solution was significantly reduced and a fast calcinations profile was realized.

YBCO coated conductor has been fabricated by cost-effective wet chemical processing route. Biaxially textured Ni was formed by electro-deposition process and delaminated from the cathode for further buffer layer deposition process. Subsequently, buffer layers are deposited by MOD process to prevent interfacial reaction between superconductor and substrates. Finally, YBCO layer was deposited on the buffered Ni substrate by MOD process using F-free Y & Cu precursor solution. The microstructure and texture development of each layers have been investigated.

**Publications:**

1. X. L. Wang et al., “Silicone oil: A liquid additive to enhance field critical current in MgB$_2$” *Applied Physics Letters* **90**, 042501 (2007);


3. J. W. Ko, J. M. Yoo et al., “MgB$_2$ tapes with Al addition were fabricated by PIT method”, *Physica C*, in press;

5. Y. K. Kim, J. M. Yoo et al., “All electro/chemical processing of YBCO coated conductor”, IEEE superconductivity, in press.

The role of nano-structures for the super-current flow and limitation in high-temperature superconducting films and multi-layers

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<td>Partner Investigator:</td>
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The aim of the project is the development of the second generation of high-temperature superconductors for electrical power engineering. The comprehension of critical current density limiting mechanisms in films and multi-layers, as well as the construction of corresponding theoretical models will be the main scientific outcome of the project.

Reciprocal research visits have been exchanged between Institute for Metal Physics and University of Wollongong by Dr. A. Kordyuk (from IMP), Dr. A. V. Pan (from University of Wollongong) and a PhD student, S. Pysarenko (from University of Wollongong). Apart from a large volume of collaborative research carried out by both parties, two seminars were given by Dr. Kordyuk on the status of the research field in general and on particularities of the ongoing research, as well as two seminars were presented at IMP and one at Kiev State University by Dr. A. V. Pan, and one seminar was presented by the PhD student (S. Pysarenko) on the status of the PhD research work relevant to the project.

High temperature superconducting YBa2Cu3O7 films with various thicknesses have been prepared by pulsed laser deposition method with different deposition rates. The thickness dependence of critical current density Jc evolves with magnetic field, temperature and deposition rate. Changes in Jc behaviour observed are explained on the basis of monitoring the surface morphology transformation for samples with different thicknesses. The surface microstructure is shown to degrade significantly with increasing thickness. The Jc behaviour variation in films of different thicknesses grown with different speeds is explained by changing (degrading) microstructure from the bottom layers to the top ones. The vortex pinning is shown to be governed in films of arbitrary thicknesses mainly by the layers which are situated below about 600 nm. In the thicker films, Jc is mostly affected by the competition between microstructure degradation and the enlargement of the effective cross section for the current flow. Jc(Bc)-dependencies were measured for magnetic fields parallel and perpendicular to the crystal axes of the films and demonstrate Jc-plateau at fields below some certain value Bm. A few important peculiarities has been noted: (1) the plateau for the field perpendicular to the films - appears to be much longer than for the parallel orientation; (2) a peak-effect is observed at the parallel field orientation at the upper-field end of the plateau before the onset of the degradation of Jc with field in the most optimal films; (3) Jc degradation in parallel fields is steeper. The Jc(Bc) curves were obtained by ac magnetic susceptibility technique and corresponding Clem-Sanchez analysis of the data. Similar results for Jc in parallel fields are obtained by transport current four-probe technique and dc magnetization measurements. The absence of the maximum in angular Jc dependences for at a certain perpendicular field region has been shown to be the consequence of the shorter Jc plateau than for the parallel fields. In the perpendicular case Bm was shown to be determined by the accommodation function of the Abrikosov vortex lattice on the edge dislocations and may be rather low for optimal epitaxial films with large single-crystalline domains. In contrast, for the parallel field orientation, Bm turned out to depend on surface Meissner currents induced by the parallel field tending to bend the ends of all vortices out from dislocation cores and to diminish the total pinning force. In this case Bm is the field for which the value of the Meissner current at the film surface equalizes to the critical current in the zero field. The observed peak-effect at the parallel field orientation along with the observed hysteresis depending on magnetic and geometric history was found to result from the surface (and/or geometrical) barrier providing additional pinning source for Abrikosov vortices.

We have also carried out a series of angular resolved photoemission spectroscopy on HTS materials, which is important to establish the electronic properties in these materials. The quantity of special interest is a quasi-particle scattering rate or, more precisely, the single-particle self-energy, the real part of which can be associated with the mass renormalization and the imaginary part is proportional to the scattering rate or, in the simplest Drude model, to the normal-state resistivity. The true lowest value of the energy taken at the Fermi level is important to know in order to reconcile the parameters of quasi-particle spectrum with transport measurements, but its behaviour at low energy and temperature, is vital to judge whether the quasi-particle approach is applicable to describe the electronic properties of HTSC. Thus, by fitting the momentum distribution photoemission spectra to the Voigt profile appeared to be a robust procedure to purify the interaction effects from the experimental
resolution. In application to Bi$_2$Sr$_2$CaCu$_2$O$_8$ high-$T_c$ cuprates, the procedure reveals the true scattering rate at low binding energies and temperatures, and consequently, the true value of the elastic scattering. Reaching the minimal value of 16 meV, the elastic scattering does not reveal a systematic dependence on doping level, but is rather sensitive to impurity concentration and can be explained by the forward scattering on out-of-plane impurities. The inelastic scattering is found to form well-defined quasi-particles with the squared and cubic scattering rates, above and below $T_c$, respectively.

Publications:


Photon induced nonlinear absorption and transport in semiconductor nanostructures

Funded: 2005 2006 2007
Project ID: LX0559621
Chief Investigators: C. Zhang – University of Wollongong
Partner Investigator: J. C. Cao – Chinese Academy of Science

The aim of this project is to study the photon induced transport in electronic systems and the potential application of this photo-transport in optoelectronic devices. In 2005 we studied the terahertz absorption in single-walled carbon nanotubes. It was found that a weak impurity potential can lead to a strong above-gap absorption continuum. The total absorption is enhanced due to the intraband and indirect transitions, as well as plasmon excitations, which are forbidden in perfect nanotubes. Such impurity induced absorption is strongly dependent on the size and chirality of the tube. The CI, C. Zhang, visited the Chinese Academy in 10/2006. He gave a lecture at the Academy and discussed with the CAS group on the terahertz absorption in carbon nanotubes. The PI, J. C. Cao, visited UoW group in 08/2006. The main accomplishment of this visit was the development of computing code for nanotubes and completion of the first joint publication of the project. The paper was subsequently accepted and published in Applied Physics Letters.

Publications:


Terahertz optoelectronics based on spintronics materials

Funded: 2005 2006 2007
Project ID: LX0668576
Chief Investigators: C. Zhang – University of Wollongong
D. Abbott – University of Adelaide
Partner Investigator: C. Zhang – Rensselaer Polytechnic Institute, USA

Research progress in 2006:

The CI Zhang has developed a model for two-colour terahertz emission using spintronic materials. The model is based on the electron-hole bi-layer structure with Rashba spin-orbit coupling. The PhD student from University of Adelaide, Ms. Gretel Png, spent three months at PI’s Centre for terahertz research. During this short period of time, she worked hard to squeeze in a variety of challenging tasks: she has learnt to use a terahertz (THz) system, sorted out many logistical issues pertaining to biological experiments, and also ran very preliminary experiments that have so far shown great promise for cancer detection.
Two conference papers have been submitted based on the work done during this visit. (1) Molecular and Structural Preservation of Dehydrated Bio-Tissue for THz Spectroscopy, submitted to SPIE Smart Materials, Nano- and MicroSmart Systems 2006 (2) Creams and Oils: Possible THz Coupling Media for Rough Surfaces, presented at IRMMW-THz 2006, (09/2006. Shanghai, China)

5. Progress Reports on ARC Linkage Infrastructure and Equipment grants

Enhancing Australia's Terahertz Infrastructure

Funded: 2006 2006 2007
Project ID: LE0050580

Good progress has been made on this project in 2006. The investigators have determined the optimum equipment to purchase given the rapid developments in THz technology since the application was submitted. The final decision has been to develop a state-of-the-art, high-resolution, two-colour system. After protracted negotiations, an excellent room in which the lasers will be installed has been secured adjacent to the existing laser laboratories. Fitting out of this room is in progress. Most of the equipment items have been received or are on order.
Pressure-Induced Transition in Magnetoresistance of Single-Walled Carbon Nanotubes

We applied hydrostatic pressure (up to 10 GPa) to single-walled carbon nanotube bundles at low temperature (down to 2 K) to measure their magnetoresistance (MR) in a field up to 12 T. We found a pressure-induced transition in MR from positive to negative in the high-field regime. The onset of the transition occurs at ~1.5 GPa, which correlates closely with the tube shape transitions. The characteristics of the high-pressure MR are consistent with a model of pressure-induced two-dimensional weak localization.

Transport of spin-polarized electrons in a magnetic superlattice
J. F. Liu, W. J. Deng, K. Xia, C. Zhang, and Z. S. Ma

We investigated the ballistic transport of two-dimensional electrons subjected to a periodically modulated magnetic field in the presence of the spin-orbit coupling of both the Rashba and the Dresselhaus types. It is shown that the spin splitting leads to additional gaps in the band structure and a series of minima in the transmission probability. The boundaries of the superlattice cause a finite spin polarization which can be tuned by the magnetic field, the electronic energy, and the superlattice period. The potential of such magnetic modulated structures as spin filters is discussed.

Shot noise and conductance in metallic carbon nanotubes in the presence of correlated defects
Q. Zhang, H. Yang, C. Zhang, and Z. S. Ma

We investigate the effect of isolated scattering centers on the electronic transport in metallic carbon nanotubes. It is found that the impurity potential significantly alters the overlap of electronic wave functions and results in a rapid oscillation in the conductance and the shot noise. Furthermore, the conductance and the shot noise near the neutral Fermi energy depend periodically on the relative position of the scatterers and on the phase factor $\phi$ which is generated by the scattering. If two defects are in the same sublattice and $\Delta d >> a_s$, the conductance near the neutral Fermi energy is dropped to $G_0 = 2e^2/h$ approximately and the shot noise decreases to zero when $\phi = 0$ or $\phi = \pi$; whereas, the situation is reversed for the configuration in which two defects are in the different sublattices. For the case of closely paired defects, it is predicated that a small “energy gap” would be developed in “metallic” nanotubes. A comparison of our numerical results and the analytical calculations of the effective-mass approximation are presented.

Optical spectrum of a two-dimensional hole gas in the presence of spin-orbit interaction

We present a theoretical study on how the Rashba type of spin splitting affects the optical spectrum of a two-dimensional hole gas (2DHG) realized from a $p$-type GaAs/Al$_x$Ga$_{1-x}$As heterojunction. The optical conductivity is evaluated on the basis of the Kubo formula and a standard random-phase approximation for hole-hole interaction in different spin branches. It is found that similar to the case of a spin-split two-dimensional electron gas (2DEG), the optical spectrum of a spin-split 2DHG depends strongly on two optic like plasmon modes caused by collective excitation between two different spin branches. The position and width of the absorption spectrum relate directly to important spintronic coefficients. Thus, the spin splitting induced by the Rashba effect can be identified optically and important spintronic properties of a 2DHG can be measured via optical experiments. The results are also compared to those obtained for a spin-split 2DEG.

Two colour plasmon excitation in an electron-hole bi-layer structure controlled by the spin-orbit interaction

40
The dispersion and intensity of coupled plasma excitation in an electron-hole bi-layer with Rashba spin-orbit coupling is calculated. We propose to use the spin-orbit coupling in individual layers to tune the intensity of two plasmons. The mechanism can be used to develop a two colour terahertz source with tuneable intensities.

Fiber-optic temperature sensor based on interference of selective higher-order modes
E. B. Li, X. L. Wang, and C. Zhang

A fiber-optic temperature sensor based on the interference of selective higher-order modes in circular optical fibers is described. The authors demonstrate that by coupling the LP_{01} mode in a standard single-mode fiber to the LP_{0m} modes in a multimode fiber, and utilizing the interference of the higher-order modes, a fiber-optic temperature sensor which has an extremely simple structure and is suitable for high-temperature measurements can be constructed. The sensing principle, temperature measurement experiments, and results are presented.

Thermionic cooling in cylindrical semiconductor nanostructures
P. Lyu and C. Zhang

The authors analysed the thermionic cooling efficiency of the cylindrical semiconductor nanostructures. It is shown that due to the reduced emission current from the inner electrode, the cooling efficiency can be enhanced if the outer cylinder is the cold electrode. The threshold voltage for thermionic cooling is lower in cylindrical devices as compared to that in planar devices. The competition between the heat transport by electrons and the heat conduction by phonons is responsible for the efficiency enhancement and the voltage reduction.

Optical absorption coefficients in two-dimensional semiconductors under strong magnetic field
L. Y. Yu, J. C. Cao, and C. Zhang

We calculate the photon absorption coefficient of hot two-dimensional electrons in the presence of a strong magnetic field. The electrons interact strongly with the optical phonons and the acoustic phonons in quantum wells. The dependence of the optical absorption on the magnetic field is obtained by using the quantum mechanical kinetic theory. It is found that the photon absorption spectrum displays a local magnetophonon resonance. The magnetophonon absorption resulting from inelastic scattering between Landau levels is more pronounced at higher temperature. The effect of subband nonparabolicity on the absorption coefficient is also discussed.

Frequency-dependent Hall effect in spintronic systems under zero magnetic field
C. Zhang, Z. S. Ma, and W. Xu
Physica E 34, 321 (2006)

It is shown that in an electronic system with finite Rashba coupling and in the absence of external magnetic field, the Hall resistivity ($\rho_{xy}$) is finite at both zero and finite frequencies. This Hall resistivity is determined by the reactive part (real part) of the inverse dielectric functions. This allows us to probe the real part of the dielectric function in a spintronic system by using a transport measurement.

Fast-electron optical spectrum of a two-dimensional electron gas in the presence of the Rashba effect
W. Xu, Z. Zeng, F. Lu, and C. Zhang
Physica E 34, 272 (2006)

We examine how the Rashba spin-orbit interaction (SOI) affects the fast-electron optical spectrum of a two-dimensional electron gas (2DEG). It is found that for a spin-split 2DEG, the spectrum of optical absorption is mainly induced by plasmon excitation via inter-SO electronic transition. From the width and position of the spectrum, the Rashba spin-splitting can be identified optically and, therefore, important spintronic properties can be measured though optical experiments.
Improved Jc of MgB2 superconductor by ball milling using different media
X. Xu, J. H. Kim, W. K. Yeoh, Y. Zhang, and S. X. Dou

In this paper, the effects of ball milling boron (B) powders using different media, such as acetone, ethanol, and toluene, on the superconducting properties of MgB2 have been studied. It was observed that toluene medium was the most effective of them all for enhancing Jc. Jc was estimated to be 5 x 10^3 A cm⁻² at 8 T and 5 K. This value is much higher than that of pure MgB2 that was not ball milled, by a factor of 20. It was considered that ball milling B using toluene leads to smaller MgB2 grains, resulting in enhanced Jc at low operating temperature and high field.

Magnetic field processing to enhance critical current densities of MgB2 superconductors

A magnetic field of up to 12 T was applied during the sintering process of pure MgB2 and carbon nanotube (CNT) doped MgB2 wires. The authors have demonstrated that magnetic field processing results in grain refinement, homogeneity, and enhancement in Jc(H) and Hirr. The extent of improvement in Jc increases with increasing field. The Jc for a 10 T field processed CNT doped sample increases by a factor of 3 at 10 K and 8 T and at 20 K and 5 T, respectively. Hirr for the 10 T field processed CNT doped sample reached 9 T at 20 K, which exceeded the best value of SiC doped MgB2 at 20 K. Magnetic field processing reduces the resistivity in CNT doped MgB2, straightens the entangled CNTs, and improves the adherence between CNTs and the MgB2 matrix.

Superconductivity of MgB2 with embedded multiwall carbon nanotube

We studied the effects of MgB2 with embedded multiwall carbon nanotubes (MWCNTs) on the crystallinity, lattice parameters, critical current density (Jc), upper critical field (Hc2), irreversibility field (Hirr), and microstructure of MgB2. Fe sheathed un-doped and MWCNT doped MgB2 wires were fabricated by the powder-in-tube (PIT) method and sintered at the high sintering temperatures of 900 °C. We observed that for the MWCNT doped sample high temperature sintering resulted in depressed crystallinity, shrinkage of the a-lattice parameter, higher Jc up to 12 T and lower critical temperature (Tc) values. Specifically, MWCNT doped samples sintered at 900 °C exhibited excellent Jc similar to 10^4 A·cm⁻² up to 9 T at 4.2 K. This can be explained by lattice distortion and poor crystallinity due to carbon (C) substitution from the MWCNT.

 Enhancement of in-field Jc in MgB2/Fe wire using single and multiwalled carbon nanotubes

The authors investigated the doping effects of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) on the Tc, lattice parameters, Jc(B), microstructure, and Hc2 of MgB2/Fe wire. These effects systematically showed the following sequence for Tc and the a axis: the SWCNT doped wire < the MW short CNT doped wire < the MW long CNT doped wire < undoped wire, while Jc(B) followed the sequence of the SWCNT doped wire > the MW short CNT doped wire > the MW long CNT doped wire > undoped wire. A dominating mechanism behind all these findings is the level of C substitution for B in the lattice.

Effect of boron powder purity on superconducting properties of MgB2

The effect of the properties of starting boron powders on the superconducting properties of MgB2 has been studied. The 92% and 96% pure powders produce lower surface reactivity and larger particle size than the 99% boron powder, as can be seen from Brunauer - Emmett - Teller (BET) and scanning electron microscopy (SEM) results, indicating that the low purity powders cannot be used to archive the same superconducting properties as those of samples made from pure 99% boron powder. However, the purity of 92% and 96% boron powders can be improved by using a simple chemical process, leading to enhanced magnetic critical current densities Jc. From
Control of nano carbon substitution for enhancing the critical current density in MgB$_2$


The effects on transition critical temperature, lattice parameters, critical current density, and flux pinning of doping MgB$_2$ with carbon nanoparticles, were studied for bulk, wire and tape under a wide range of processing conditions. Under the optimum conditions, magnetic $J_c$ was enhanced by two orders of magnitude at 5 K for a field of 8 T, and by a factor of 33 at 20 K for a field of 5 T for bulk samples, whereas enhancement by a factor of 5.7 was observed in the transport $I_c$ at 12 T and 4.2 K for a wire sample. Samples sintered at high temperature (900 and 1000 °C) exhibited excellent $J_c$, approximately 10 000 A cm$^{-2}$ in fields up to 8 T at 5 K. This result indicates that flux pinning was enhanced by the carbon substitution for B with increasing sintering temperature. Highly dispersed nanoparticles are believed to enhance the flux pinning directly, in addition to the introduction of pinning centres by carbon substitution. Nano-C is proposed to be one of the most promising dopants besides SiC and CNT for the enhancement of flux pinning for MgB$_2$ in high fields.

The doping effect of multiwall carbon nanotube on MgB$_2$/Fe superconductor wire


We evaluated the doping effect of two types of multiwall carbon nanotubes (CNTs) with different aspect ratios on MgB$_2$/Fe monofilament wires. Relationships between microstructure, magnetic critical current density ($J_c$), critical temperature ($T_c$), upper critical field ($H_{c2}$), and irreversibility field ($H_{irr}$) for pure and CNT doped wires were systematically studied for sintering temperature from 650 to 1000 °C. As the sintering temperature increased, $T_c$ for short CNT doped sample slightly decreased, while $T_c$ for long CNT doped sample increased. This indicates better reactivity between MgB$_2$ and short CNT due to its small aspect ratio, and substitution of carbon (C) from short CNT for boron (B) occurs. In addition, short CNT doped samples sintered at high temperatures of 900 and 1000 °C exhibited excellent $J_c$, and this value was approximately $10^4$ A/cm$^2$ in fields up to 8 T at 5 K. This suggests that short CNT is a promising carbon source for MgB$_2$ superconductor with excellent $J_c$. In particular, inclusion of nanosized MgO particles and substitution of C into the MgB$_2$ lattice could result in strong flux pinning centers.

Alignment of carbon nanotube additives for improved performance of magnesium diboride superconductors


A method for aligning carbon nanotubes (CNTs) in CNT-MgB$_2$ superconductor composite wires through a readily scalable drawing technique is described. The aligned CNT-doped MgB$_2$ wires show an enhancement in magnetic critical current density by more than an order of magnitude in high magnetic fields compared to undoped wires. The arrows in the figure indicate CNTs in the composite.

Improving flux pinning of MgB$_2$ by carbon nanotube doping and ultrasonication

W. K. Yeoh, J. H. Kim, J. Horvat, S. X. Dou, and P. Munroe


Carbon nanotubes (CNTs) are an excellent candidate for introducing effective pinning centres and at the same time enhancing the upper critical field of MgB$_2$. We report on the use of a low intensity ultrasonication as a method of dispersion of CNTs into precursor magnesium and boron powder. The ultrasonication improved homogenous mixing of CNTs with the MgB$_2$ matrix. Ultrasonication of CNT doped MgB$_2$ resulted in a significant enhancement in the field dependence of critical current density. The density of the sample increased due to the improved adherence between CNTs and MgB$_2$ matrix. CNTs donate carbon that is substituted for boron in MgB$_2$. 

x-ray diffraction (XRD) measurement, oxide impurity has been observed, which might be originated from the B$_2$O$_3$ phase in the boron powders. In order to get high performance MgB$_2$, it is obviously important to control the phase composition and microstructure of amorphous boron starting powders and solid reaction conditions.
An alternative method for determination of the lock-in angle in twinned superconductors
S. Keshavarzi, J. Horvat, A. V. Pan, M. J. Qin, S. X. Dou, X. Yao, and P. Munroe

An alternative method for determining the lock-in angle $\Phi_L$ for pinning of the vortices on extended defects has been developed. This method does not require any preassumed criterion for defining $\Phi_L$. Highly twinned Sm$_{1+}$Ba$_2$Cu$_3$O$_{6+}$, single crystal was used for demonstrating the method. Appropriate scaling of the hysteresis loops measured for different angles between the field and twin planes in highly twinned SmBaCuO single crystal led to a clear discrimination between two vortex dynamics regimes. From this scaling, the lock-in angle was determined to be $6^\circ\pm0.1^\circ$ for the single crystal investigated. This method significantly reduces the uncertainty in determining the lock-in angle when compared to all the other currently employed methods.

Significant improvement of activation energy in MgB$_2$/Mg$_2$Si multilayer films
Y. Zhao, S. X. Dou, M. Ionescu, and P. Munroe

We obtained MgB$_2$/Mg$_2$Si multilayer structure by sequentially switching a stoichiometric MgB$_2$ target and a Si target during off-axis pulsed-laser deposition (PLD). The transmission electron microscope (TEM) cross-sectional image of the resulting film exhibits a layered structure with each MgB$_2$ layer being 40-50 nm thick and the Mg$_2$Si interlayers about 5 nm thick. A clearly enhanced anisotropy in the irreversibility lines and the vortex activation energy was observed. Pinning and the flux flow activation energy are significantly increased in parallel applied fields.

Transport properties of multilayered MgB$_2$/Mg$_2$Si superconducting thin film
Y. Zhao, M. Qin, S. X. Dou, M. Ionescu, and P. Munroe

Abstract: Electronic transport measurements have been carried out on superconducting MgB$_2$/Mg$_2$Si multilayer film, using a standard 4-probe method in perpendicular and parallel applied fields. The film, which was prepared by pulsed-laser deposition, has a layered structure with each MgB$_2$ layer being 40-50 nm thick and the Mg$_2$Si interlayers about 5 nm thick. The flux flow activation energy is deduced from the resistivity-temperature curves using an Arrhenius fit. The results show a clearly enhanced anisotropy of the vortex activation energy in the multilayered film. The irreversibility field and the vortex activation energy are significantly increased in parallel fields.

Nanomaterials for Lithium-Ion Rechargeable Batteries
Hua Kun Liu*, Guo Xiu Wang, Zaiping Guo, Jiazhao Wang, and Kosta Konstantinov

In lithium-ion batteries, nanocrystalline intermetallic alloys, nanosized composite materials, carbon nanotubes, and nanosized transition-metal oxides are all promising new anode materials, while nanosized LiCoO$_2$, LiFePO$_4$, LiMn$_2$O$_4$, and Li$_4$Ti$_5$O$_12$ show higher capacity and better cycle life as cathode materials than their usual larger-particle equivalents. The addition of nanosized metal-oxide powders to polymer electrolyte improves the performance of the polymer electrolyte for all solid-state lithium rechargeable batteries. To meet the challenge of global warming, a new generation of lithium rechargeable batteries with excellent safety, reliability, and cycling life is needed, i.e., not only for applications in consumer electronics, but especially for clean energy storage and for use in hybrid electric vehicles and aerospace. Nanomaterials and nanotechnologies can lead to a new generation of lithium secondary batteries. The aim of this paper is to review the recent developments on nanomaterials and nanotechniques used for anode, cathode and electrolyte materials, the impact of nanomaterials on the performance of lithium batteries, and the modes of action of the nanomaterials in lithium rechargeable batteries.

Highly Reversible Lithium Storage in Spheroidal Carbon-Coated Silicon Nanocomposites as Anodes for Lithium-Ion Batteries
See-How Ng, Jiazhao Wang, David Wexler, Konstantin Konstantinov, Zai-Ping Guo, and Hua-Kun Liu
Spheroidal carbon-coated Si nanocomposite, prepared by a spray-pyrolysis method in air, is a promising candidate for use as an anode material in lithium ion batteries, as it has excellent retention of specific capacity of 1489 mAh/g after 20 cycles, high coulombic efficiency, and low cost (because of the abundance of both Si and carbon sources).

Figure 1. TEM images of spheroidal carbon-coated Si nanocomposites produced by spray pyrolysis in air: a) low-magnification image of a sample produced at 400°C, with the indexed diffraction pattern (inset) confirming the presence of Si nanoparticles; b) high-resolution image showing the carbon-coated Si nanocomposite, with the inset showing the interface between a crystalline Si particle and the pyrolyzed carbon coating layer (ca. 10 nm thickness).

Nanostructured PbO materials obtained in situ by spray solution technique for Li-ion batteries
K. Konstantinov, S. H. Ng, J. Z. Wang, G. X. Wang, D. Wexler, and H. K. Liu

This paper describes a systematic study of the effect of various spray pyrolysis parameters, such as temperature, solution concentration and solution flow rate on the morphology, crystallization process, crystal size, specific surface area and electrochemical performance of in situ prepared α-PbO spherically agglomerated nanostructured powders. Different analytical methods such as XRD, SEM, TEM, BET gas sorption specific surface area measurements and electrochemical tests were performed. Crystallites in the range of 20–120 nm and easily dispersed powders were reproducibly prepared by optimization of the spray conditions. An increase of the temperature from 600 to 800 °C was found to lead to a three times increase in the average crystal size, from 31 to 102 nm. An increase of concentration from 0.15 to 0.5 M dramatically suppresses the crystal size from 127 to 25 nm. The BET surface area of sprayed PbO powders is increased up to 6.6 m² g⁻¹. For such PbO powders applied as anode materials in Li-ion batteries, we have managed to retain a reversible capacity above 60 mAh g⁻¹ beyond 50 cycles.

Synthesis and characterization of nanosize cobalt sulphide for rechargeable lithium batteries
J. Wang, S. H. Ng, G. X. Wang, J. Chen, L. Zhao, Y. Chen, and H. K. Liu

Nanosize cobalt sulphides were synthesized through a one step chemical reaction method at room temperature. The cobalt sulphide nanopowders were characterized by X-ray diffraction, energy dispersive X-ray spectroscopy, scanning electron microscopy and electrochemical testing. The results revealed that the cobalt sulphide is a semiconductor; the reversible capacity is increased with increasing content of electronic conductors in the active material of electrodes. The as prepared sample with 10 wt% carbon black and 10 wt% polypyrrole (Ppy) powder as electronic conductors shows the best electrochemical properties, with a reversible capacity of over 300 mAhg⁻¹ based on the total mass of the electrode. Cobalt sulphide nanopowders show promise as cathode active materials for lithium rechargeable batteries.

Lithium/Polymer Battery based on Polybithiophene as Cathode Materials
Polybithiophene film coated stainless steel mesh electrodes, obtained by electrochemical polymerization (constant potential (CP) and constant current (CI)), has been investigated as cathode materials in the lithium/polybithiophene rechargeable battery by cyclic voltammetry, electrochemical impedance spectroscopy and long-term charge-discharge process. The effect of different growth methods on surface morphology of films and charge-discharge capacity are discussed in detail. The results show that polybithiophene-hexafluorophosphate grown by constant potential from dichloromethane (DCM) has the high stable charge-discharge performance with a discharge capacity of 81.67 mAh/g observed after 50 cycles.

**Sulphur-polypyrrole composite positive electrode materials for rechargeable lithium batteries**


A novel conducting sulphur-polypyrrole composite material was prepared by the chemical polymerization method with sodium p-toluenesulfonate as the dopant, 4-styrenesulfonic sodium salts as the surfactant and FeCl3 as the oxidant. The new material was characterized by Raman spectroscopy, thermogravimetric analysis and scanning electron microscopy. Nanosize polypyrrole particles were uniformly coated onto the surface of the sulphur powder, which significantly improved the electrical conductivity, the capacity and the cycle durability in a lithium cell compared with the bare sulphur electrode.

**An investigation on electrochemical behaviour of nanosize zinc sulphide electrode in lithium-ion cells**

*J. Z. Wang, G. X. Wang, L. Yang, S. H. Ng, and H. K. Liu*


Nanosize zinc sulphides were synthesized through the chemical reaction method. The as-prepared ZnS nanopowders were characterized by X-ray diffraction, transmission electron microscopy and electrochemical testing. The results revealed that ZnS electrodes exhibited a reversible lithium storage capacity of about 400 mAh g⁻¹ with stable cycle ability. ZnS nanopowders show promise as anode materials for lithium-ion batteries.

**Synthesis of vanadium pentoxide powders with enhanced surface-area for electrochemical capacitors**

*Z. J. Lao, K. Konstantinov, Y. Tournaire, S. H. Ng, G. X. Wang, and H. K. Liu*

*Journal of Power Sources* 162 1451 (2006)

Single-phase, chemically pure vanadium pentoxide (V₂O₅) powders are prepared by co-precipitation and further calcination at 300 °C. The materials obtained are agglomerated in sub-micron particles, and BET analysis shows that the as-prepared V₂O₅ powders have a high specific surface-area of 41 m² g⁻¹. V₂O₅ shows the highest capacitance in 2 M KCl electrolyte when compared with other electrolytes such as 2 M NaCl and 2 M LiCl. It yields a maximum specific capacitance of 262 F g⁻¹. The higher specific surface-area may be the reason for the high capacitance compared with previously published results.

**Low thermal conductivity short-period superlattice thermionic devices**

*M. F. O'Dwyer, T. E. Humphrey, R. A. Lewis, and C. Zhang*


Most models of solid-state thermionic devices assume that all electrons with energy in the direction of transport greater than the barrier height are transmitted and utilize the Richardson equation. Here we consider a number of thermionic systems where the electron energy spectrum differs from the Richardson model. The electron energy spectra for maximum refrigeration coefficient of performance and maximum power are presented. We then consider multilayer solid-state nanostructures with currents not given by the Richardson equation and discuss the optimization of their energy spectrum. Nanometre gap vacuum thermionic refrigerators are also treated, where significant current is provided by below the barrier tunnelling. Finally, equations are developed for devices that select electrons for emission according to their total momentum, rather than simply the value in the direction of transport as is the case with conventional devices.

**THz generation in InAs**

*R. A. Lewis, M. L. Smith, R. Mendis, and R. E. M. Vickers*


We have observed strong terahertz (THz) emission from the o1 0 04 face of p-type InAs when it is illuminated by
ultrashort (<12 fs) pulses of near-infrared radiation. As the crystal is rotated about the surface normal, there are two maxima per rotation, suggesting optical rectification plays a role in the emission process. This holds whether the angle of incidence is 45°, most convenient for technical application, or 75°, the Brewster angle, where the THz output is strongest. The power of the THz radiation varies approximately quadratically with the pump power. The data are consistent with photocurrent surge being the main mechanism of THz emission. We have found that the p-type InAs produces about two orders of magnitude more power than a standard unbiased THz emitter, 1-mm thick ZnTe.

**Magneto-spectroscopy to 30 T of donor states in InP**
R. A. Lewis, P. E. Simmonds, and Y.-J. Wang

Far-infrared absorption spectroscopy in the energy range 100–400 cm⁻¹ is reported for donors in indium phosphide at 4.2 K in magnetic fields of up to 30 T. Transitions are observed from the bound-electron ground state to both stable and metastable excited states in good agreement with the effective-mass theory. At the highest magnetic fields employed, corresponding to 2≤g<3, several absorption features are observed just above the TO-phonon energy, 5 effective Rydberg. These are attributed to the magnetopolaron interaction and cyclotron resonance.

**Enhanced electrical polarization and ferromagnetic moment in a multiferroic BiFeO₃/Bi₃.25Sm₀.75Ti₂.98O₁₂ double-layered thin film**

Multiferroic BiFeO₃/Bi₃.25Sm₀.75Ti₂.98O₁₂ double-layered thin films on Pt/Ti/SiO₂/Si were fabricated using the pulsed-laser deposition technique. The films showed greatly enhanced ferroelectric and ferromagnetic properties. The values of the remanent polarization (2P_r) and coercive field (E_c) were 71.8 μC/cm² and 148 kV/cm at a maximum applied voltage of 13 V, respectively. The value of the magnetic moment was found to be 17.5 emu/cm³. The enhancement of the polarization originated from the BiFeO₃ with Bi₃.25Sm₀.75Ti₂.98O₁₂ working as a barrier layer. The enhancement of the magnetization is from the structural distortion of BiFeO₃, due to partial epitaxial growth on the bismuth titanate surface.

**Orientation dependent ferroelectric properties in samarium doped bismuth titanate thin films grown by the pulsed-laser-ablation method**
Z. X. Cheng, C. V. Kannan, K. Ozawa, H. Kimura, and X. L. Wang

Samarium doped bismuth titanate thin films with the composition of Bi₃.25Sm₀.75Ti₂O₁₂ and with strong preferred orientations along the c-axis and the (117) direction were fabricated on Pt/TiO₂/SiO₂/Si substrate by pulsed-laser-ablation. Measurements on Pt/BSmT/Pt capacitors showed that the c-axis oriented film had a small remanent polarization (2P_r) of 5 μC/cm², while the highly (117) oriented film showed a 2P_r value of 54 μC/cm² at an electrical field of 268 kV/cm and a coercive field E_c of 89 kV/cm. This is different from the sol-gel derived c-axis oriented Bi₃.15Sm₀.85Ti₃O₁₂ film showing a 2P_r value of 49 μC/cm².

**Quantum Effects in Small-Capacitance High Temperature Superconducting Tunnelling Junctions**
G. A. Alvarez, I. Iguchi, X. L. Wang, and S. X. Dou

We investigated for the first time the effects of single electron charging energy in high temperature superconductors (HTS). Various phenomena originating from Coulomb blockade were observable in superconducting tunnel junctions. High quality tunneling junctions were fabricated from c-axis oriented NdBa₂Cu₃O₇-s/PrBa₂Cu₃O₇-δ/NdBa₂Cu₃O₇-δ (NBCO/PBCO/NBCO) thin film multilayers by the Pulsed Laser Deposition method. The current-voltage characteristics (CVC) show a Coulomb gap for Cooper pair tunnelling when the charging energy exceeds the Josephson coupling energy. We found a regime in which the CVC exhibit sharply defined Coulomb steps due to single electron dynamics and non-linear tunnelling rates. From the obtained Coulomb staircase, the tunnelling conductance shows a novel quantum effect: it is modulated by the tunnelling current in the form h/4e²R₀−[sin(πI/I₀)²/πI/I₀]. We suggest an interpretation involving the quantum resistance h/e² and the competition between the charging, Josephson and thermal energies of the system. Our
results give a new perspective on a solid-state quantum system with considerable interest for direct application in quantum computing.

**Spectroscopic Measurements of Zeeman Splitting of the Density of States in High Temperature Superconducting Multilayer Tunnelling Junctions**

*G. A. Alvarez, I. Iguchi, X. L. Wang, and S. X. Dou*


We report c-axis tunnelling spectroscopy investigations in high magnetic fields (I-V characteristics and tunnelling conductance dI/dV) of high quality planar junctions fabricated from c-axis oriented NdBa$_2$Cu$_3$O$_{7-δ}$/PrBa$_2$Cu$_3$O$_{7-δ}$ thin film multilayers. These high temperature superconducting (HTS) tunnelling junctions provide for the first time a spectroscopic magnetic field splitting of the quasi-particle states. The magnetic field splitting of the quasi-particle states allows us to determine the size of spin-orbit interactions in HTS multilayer tunnelling junctions. The tunnelling conductance in a parallel magnetic field reveals Zeeman splitting of the quasi-particle density of states. In the presence of spin orbit interactions, our measurements for the tunnelling density of states and the tunnelling conductance show a spin splitting of $g\mu_B H$ in energy space of the density of states peak. Here the quantity $\mu_B$ is the Bohr magneton, $g$ is the $g$-factor of the electron and $H$ is the applied magnetic field. The magnitude of the splitting is attributed to the magnetic moment of the quasi-particles. The spin splitting of the density of states in HTS multilayer tunnelling junctions could be used as a very powerful technique to determine the relative spin polarization in magnetic materials.
Current & Ongoing Research Projects

Funded ARC Projects in 2006 round at ISEM

ARC Centre of Excellence

Nano-materials for energy storage

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<td>Postgrad Students:</td>
<td>S. H. Ng, M. Park</td>
<td></td>
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ARC Large/Discovery Grants Scheme

First Principles for Development of High Temperature Superconducting Wires

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<td>S. X. Dou, J Horvat</td>
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<td>Assoc. Investigator:</td>
<td>H. Weber, E. W. Collings, J. Habermeier</td>
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<tr>
<td>Postgrad Student:</td>
<td>S. Keshavarzi, M. Roussel</td>
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Significant advances in research of high temperature superconductors (HTS) have been made in the past decade. However, the full commercialisation of HTS devices has not yet been achieved because the levels of electrical performance remain just below those required for technical and commercial success. In order to secure the future of HTS it will be essential to increase the critical current density, reduce the AC losses and lower the cost. The objective of the proposed cluster of projects is to provide new insights into fundamental HTS materials properties such as critical current density, flux pinning, flux dynamics and AC losses by focusing on the complex interplay between physics, fabrication and materials issues. The knowledge gained will make possible improvements in the development of HTS conductors.

Control of Nano-Structure for Enhancing the Performance of Magnesium Diboride Superconductor by Chemical Doping

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<td>Chief Investigator:</td>
<td>S. X. Dou, M. J. Qin,</td>
<td></td>
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<tr>
<td>Partner Investigator:</td>
<td>D.C. Larbalestier, R.L. Flukiger, L.F. Cohen</td>
<td></td>
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<tr>
<td>Postgraduate students:</td>
<td>W. K. Yeoh, O. Shcherbakova, Y. Zhang</td>
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Superconductor technology will play a significant role in a wide range of industry sectors and environments in the twenty first century. Widespread applications now depend significantly on cost-effective resolution of fundamental materials and fabrication issues. The aim of the proposed program is to bring together international experts from four leading groups to tailor the microstructure at nanoscale to improve flux pinning and the critical current density of the newly discovered magnesium diboride superconductors through readily available chemical doping. The expected outcome is the capability to produce a new generation of superconductors having high performance at low cost.
Hydrogen storage materials for energy conversion applications

Funded: 2004 2005 2006
Amount Funded: $85,000 $85,000 $85,000
Total Funding: $255,000
Project ID: DP0449660
Chief Investigator: H. K. Liu, Z. P. Guo
Partner Investigator: J. Lee, A. Zuetel, P. H. Notten
APD: Z. P. Guo
Postgraduate students: Z. G. Huang

For a clean environment, the ideal synthetic fuel is hydrogen because it is lightweight, highly abundant and its oxidation product (water) is environmentally benign. However, the effective storage of hydrogen remains a scientific challenge. This project aims to develop innovative materials with high hydrogen storage capacity and long cycle life, including new composite hydrides, catalysed metal hydrides and various nanotubes. The expected outcome is the achievement of high reversible hydrogen storage capacity to meet all the demands required for energy conversion applications, in particular, for hydrogen storage/fuel-cell vehicular applications.

Development of high-temperature superconducting coated conductors by pulsed-laser deposition technique for future long-length applications

Funded: 2004 2005 2006
Amount Funded: $70,000 $70,000 $70,000
Total Funding: $210,000
Project ID: DP0451267
Chief Investigator: A. V. Pan, M. Ionescu
APD: A. V. Pan

The aim of the project is to develop a novel technology for manufacturing flexible coated conductors with the help of a pulsed laser deposition technique, in order to enhance the current-carrying ability of high-temperature superconducting coatings (including multi-layered coatings) for future long-length high power applications. To achieve desirable electromagnetic properties governed by the nano-structures of the coatings, a well-balanced combination of world-class "global" and "local" electromagnetic property measurements with advanced structural characterisations is suggested. It is expected that a controlled network of nano-scale pinning centres will allow the development of high performance coated conductors.

Non-linear dynamics in electronic systems and devices under intense terahertz radiation

Funded: 2004 2005 2006
Amount Funded: $120,000 $140,000 $170,000
Total Funding: $430,000
Project ID: DP0452713
Chief Investigator: C. Zhang, R. A. Lewis, X. Zhang, R. E. M. Vickers

Non-linear interactions allow for a detailed and intricate probing of materials. Sufficiently high-power light directed at a subject can yield spectroscopic data about multiple material parameters, providing a unique diagnostic tool for many applications. We propose to study the non-linear dynamic properties of electronic systems and devices under various external conditions. A thorough understanding of non-linear properties will accelerate development of new optoelectronic device in the terahertz frequency regime. Examples of these devices are oscillators and sensors.

Development of new technology for coated conductors able to carry "over-critical" current densities

Years Funded: 2005 2006 2007
Total Funding: $335,000
Project ID: DP0557554
Chief Investigator: A. V. Pan, S. Zhou, Y. Genenko, T. H. Johansen
The superconductivity phenomenon has extremely attractive feature, that superconductors can carry non-dissipative currents, enabling us to reduce energy consumption by up to 50%. The new advanced method suggested in this project might give a new, fresh and inexpensive boost to not only domestic superconducting industry, but also worldwide. The development of new high performance superconductor technology would significantly promote fundamental understanding and knowledge of the poorly investigated “long-range” magnetic interaction between magnetic and superconducting materials. The University of Wollongong would lead the world research community in this practically important and scientifically intriguing area.

**Synthesis of nanowires and application as nanosensors for chemical and biological detections**

- **Years Funded:** 2005 2006 2007
- **Total Funding:** $238,000
- **Project ID:** DP0559873
- **Chief Investigator:** G. X. Wang, K. K. Konstantinov, J. Ahn, X. Q. Yang, Z. Xiao

This project is expected to bring significant scientific, economic and social benefits. We will develop a number of techniques for the controlled growth of nanowires and making functional nanoscale systems such as nanosensors. The nanosensors will have important applications in chemistry and biology. Some chemical species can be detected by nanosensors on molecular scale. The nanosensors could be used for early diagnostics of cancer disease, detection of viruses, and genomic DNA screening. The nanosensors could also provide a molecular tool for probing living cells without destroying them, through which we can track life within cells in real time.

**Exploration for new materials for spintronics**

- **Years Funded:** 2005 2006 2007 2008 2009
- **Total Funding:** $870,000
- **Project ID:** DP0558753
- **Chief Investigator:** X. L. Wang

The scope for use of spintronic materials in practical applications will be enormous and there will be a huge market for spintronic devices. In fact, giant magnetoresistance spintronic materials are already used in practical applications such as magnetic recording and storage devices. The success of this project will certainly lead to a discovery of novel magnetic semiconductor spintronic materials and better understanding of spin dependent magnetic interactions. It will enhance the international competitiveness and export power of Australian industry in the areas of information technology, quantum computing, magnetic recording and magneto-electronics.

**High efficiency terahertz emitters**

- **Year Funded:** 2006 2007 2008
- **Total Funding:** $345,000
- **Project ID:** DP0665292
- **Chief Investigators:** R. A. Lewis

Between microwaves and visible light lies the terahertz gap - the least explored region of the electromagnetic spectrum. Yet the THz region is precisely where many materials exhibit characteristic signatures that allow them to be detected and identified. For example, anthrax, explosives, water, DNA, plastics, and carcinomas all have distinctive THz signatures. THz methods are revolutionizing medicine, agriculture, industry, and national security. Wider application is hampered by the lack of powerful sources of THz radiation. We aim to develop more efficient emitters of THz radiation. The national economy, security, and well-being will benefit.

**Development of conductive buffer layers for RABiTS-based coated conductors**

- **Year Funded:** 2006 2007 2008
- **Total Funding:** $200,000
- **Project ID:** DP0666771
- **Chief Investigator:** D. Q. Shi
YBCO coated conductor has already been identified and developed as far as second generation HTS wire in power applications. Major advances have been made in the last 10 years in coated conductor development mainly in all aspects: substrate, buffer layer and YBCO layer. The research on conductive buffer layer will improve and expand the R&D on coated conductor in Australia. On the economic side, dramatic advantages and savings could be achieved if the coated conductors can be put to use. Superconductivity can have a significant role in deregulated electricity markets and in lessening CO2 emissions and other environmental impacts.

**Superconducting MgB2 thin films and structures for electronic devices and telecommunication applications**

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**Project ID:** DP0666853

**Chief Investigator:** Y. Zhao, M. Ionescu, J. Du

**Partner Investigator:** E. W. Collings

Two important directions of electronic application for MgB2 films are superconducting Josephson junction (JJ) technology and passive microwave devices. Superconducting JJ technology will have a small but important niche in high-performance digital signal and data processing applications for civilian, commercial, and military terrestrial, as well as space deployment. With superconducting passive microwave devices, the potentially largest market in this segment are filter systems for ground- or satellite based wireless communication systems. The research outcome could support Australian companies to develop corresponding products, as well as broaden Australia's knowledge of the physics of the new MgB2 superconductor.

**Development of novel ferroelectric magnetic materials for multi-functional applications**

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<th>Year Funded:</th>
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**Project ID:** DP0665873

**Chief Investigator:** X. L. Wang, Z. X. Cheng, T. Shrout, W. Wen, K. Yamaura, K. Liss, R. O. Piltz

Ferroelectric magnets having simultaneous ferroelectricity and ferromagnetism is an area of emerging scientific interest. This project is to develop novel ferroelectric magnetic materials for multifunctional applications and falls into National Research Priority, Frontier Technologies for Building and Transforming Australian Industries. This project will provide trainings for postgraduate students and develop patentable science and technologies. The scope for use of the novel multifunctional materials will be enormous with great markets in the fields of magneto-electronics, magnetic electromechanical industrial devices. It will benefit Australian manufacturing industry in the long term.
ARC Research Fellowships

Development of new technology for coated conductors able to carry "over-critical" current densities
Australian Postdoctoral Fellow: S. Zhou

Development of high-temperature superconducting coated conductors by pulsed-laser deposition technique for future long-length applications
Australian Postdoctoral Fellow: A. V. Pan

Hydrogen storage materials for energy conversion applications
Australian Postdoctoral Fellow: Z. P. Guo

Lithium/Sulphur rechargeable battery for power applications
Australian Postdoctoral Fellow: J. Wang

Exploration for new materials for spintronics
QE-II Fellow: X. L. Wang

First Principles for Development of High Temperature Superconducting Wires
Australia Professorial Fellowship: S. X. Dou

Develop highly conductive nanocomposite electrodes for Li-battery
Australia Professorial Fellowship: H. K. Liu

Superconducting MgB₂ thin films and structures for electronic devices and telecommunication applications
Australian Postdoctoral Fellow: Y. Zhao
**Strategic Partnerships with Industry - (SPIRT) Scheme - Linkage Projects & Linkage APAI**

**Lithium/Sulphur rechargeable battery for power applications**

Years funded: 2004 2005 2006  
Amount funded: $75,000 $75,000 $75,000  
Total funding: $225,000  
Project ID: LP0453698  
Chief Investigator: H. K. Liu, J. Z. Wang, G. X. Wang  
APD Award(s): J. Z. Wang  
Industry Partner(s): Guangzhou Delong Energy Technology

The Lithium/Sulphur battery system is very promising for large-scale power applications as it has the highest energy density and lowest cost among various types of rechargeable batteries. However, the degradation of the capacity and short cycle life of Li/S battery have been problematic for commercial development. The aim of this project is to study the mechanisms of capacity fading and to develop effective means such as use of carbon nanotubes and nanosize composite absorbents to improve the cycle life of Li/S batteries. The expected outcomes are the development of sulphur-containing cathode materials and polymer electrolytes, enabling electric vehicles to be a technically competitive and environmentally superior transportation option.

**Novel electric field induced coupling technique for liquid-phase heteroepitaxial growth of carbon thin films with diamond-like structure**

Years funded: 2005 2006 2007 2008  
Amount funded: $12,000 $24,000 $24,000 $12,000  
Total funding: $72,000  
Project ID: LP0561605  
Chief Investigator: S. X. Dou, A. V. Pan  
APA(I) Award(s): 1  
Industry Partner(s): Polarised Technology Pty Ltd

The aim of the project is the growth of carbon thin films with a robust diamond-like structure for high performance electronic applications via the development of a new growth technique: Electric Field Induced Coupling (EFIC), which is based on liquid-phase layer-by-layer heteroepitaxial growth. The EFIC technique employing unique polarization-induced growth will significantly enhance technological output compared to existing technologies by overcoming current difficulties with expensive and complicated production methods. Ambient temperatures and pressures employed by the technique will enable us to form diamond-based semiconductors at low cost with sufficient speed and the properties required for industrial production.

**Large-scale rechargeable lithium battery for power storage and electric vehicle applications**

Years funded: 2004 2005 2006  
Amount funded: $110,000 $110,000 $110,000  
Total funding: $330,000  
Project ID: LP0453766  
APA(I) Award(s): J. Yao  
Industry Partner(s): Pacific Lithium New Zealand Limited, Sopo Battery Energy Co., Ltd  
Postgraduate student: S. A. Needham

This project aims to develop large-scale rechargeable lithium batteries for power storage and electric vehicles. In order to achieve this target, the related cathode materials, anode materials and electrolyte systems will be developed. The design of battery modules and assembly of prototype lithium ion batteries will be performed. The success of the research will encourage the production of electrode materials and manufacture of rechargeable lithium batteries in Australia. The utilisation of advanced rechargeable lithium batteries in electric vehicles will provide sustainable energy for transportation and greatly reduce green-house emissions in Australian urban areas.
Development of Magnesium Diboride Superconductor Wires with High Upper Critical Field for MRI Applications

Years funded: 2005 2006 2007
Amount funded: $169,612 $170,861 $174,831
Total funding: $515,304
Project ID: LP0560280
Partner Investigators: K. R. McIntosh, K. M. Provancha, R. Swanson
APA(I) Award(s): 2
Industry Partner(s): Hyper Tech Research Inc Alphatech International Ltd

The aim of the program is to demonstrate the superconducting magnesium diboride (MgB$_2$) wires with improved upper critical field ($H_{c2}$) appropriate for large-scale applications. The basic idea will be based on the two-gap superconductivity to add well distributed impurities which will act as scatterers, increasing resistivity, and thus $H_{c2}$. The core innovation of this proposal is based on the recent breakthrough in MgB$_2$ that was made by the CIs through nano-SiC particle doping, which achieved a record high $H_{c2}$ in bulk form and enhancement of critical current density, $J_c$, in magnetic fields by an order of magnitude. The expected outcome is the development of superconducting MgB$_2$ wires and coils with high $H_{c2}$ and $J_c$ for MRI applications.
Photon induced nonlinear absorption and transport in semiconductor nanostructures

Years funded: 2005 2006 2007
Amount funded: $8,000 $13,000 $5,000
Total funding: $26,000
Project ID: LX0559621
Chief Investigator: C. Zhang

J. C. Cao, Chinese Academy of Sciences, China

Photon induced transport in electronic systems is of great importance in fundamental science and in development of new optoelectronics devices. In this project we aim to study the microwave radiation induced dc transport and nonlinear absorption in high mobility systems. The result will shed light on newly discovered zero-resistance state in semiconductor nanostructures. The expected outcome is an improved understanding on the mechanism of reducing dc resistance in low-dimensional electronic systems.

Molecular dynamic simulation and experimental study on the mechanisms of high critical current density in superconductors

Years funded: 2005 2006 2007
Amount funded: $11,300 $11,300 $11,300
Total funding: $33,900
Project ID: LX0560106
Chief Investigator: M. J. Qin
S. Ding, Nanjing University, China

The aim of this project is to establish collaboration between the Institute for Superconducting and Electronic Materials (ISEM) and the team at Nanjing University to study the mechanisms of high critical current density (or flux pinning) in superconductors. Molecular dynamic simulation combined with experimental techniques, such as transport and magnetic measurements will be used. The results of this work will expand our understanding of the pinning mechanisms of high temperature superconductors and MgB2 superconductors, with the hope of further enhancing the current carrying capacity, and therefore promoting the practical applications of superconductors.

Magneto-optical imaging of super-current flow in superconducting tapes and wires

Years funded: 2004 2005 2006
Amount funded: $14,140 $10,960 $11,160
Total funding: $36,260
Project ID: LX0453582
Chief Investigator: S. X. Dou, University of Wollongong
A. V. Pan, University of Wollongong
T. H. Johansen, University of Oslo

This project is aimed at establishing the connections between local and global superconducting current-carrying abilities in magnesium diboride and high temperature superconducting tapes and wires. Local high-resolution magneto-optical imaging combined with transport current techniques will be employed. Super-current streamlines and critical current density distributions will be quantitatively obtained from local magnetic flux behaviour. Pinpointing the connections is expected not only to promote production technology, but also to elucidate factors influencing the current-carrying ability in the tapes and wires.

Terahertz optoelectronics based on spintronic materials

Years funded: 2006 2007
Amount funded: $12,000 $10,000
Total funding: $22,000
Project ID: LX0668576
Chief Investigator: C. Zhang
Spintronic devices have many advantages which include non-volatility, permitting data retention in non-powered conditions, increased integration densities, high data processing speeds, low electrical energy demands, and a fabrication process compatible with those currently used in semiconductor microelectronics. The low energy consumption of spintronic devices also leads to economic and environmental benefits. Spintronic devices will help to meet the sensing and storage demands of information technology in the decades to come. The project will enhance the international competitiveness and export power of Australian industry in the areas of information technology, quantum computing, magnetic recording and optoelectronics.

**Nanostructured materials for development of advanced lithium energy storage systems**

<table>
<thead>
<tr>
<th>Years funded:</th>
<th>2006</th>
<th>2007</th>
</tr>
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<td>Project ID:</td>
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<td></td>
</tr>
<tr>
<td>Partner Investigator:</td>
<td>Y. Kim</td>
<td></td>
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</table>

This project is expected to bring several national benefits. Novel nanostructured electro active materials and high energy density rechargeable lithium batteries will be developed. The application of advanced lithium batteries as power sources for electric vehicles (EVs) and hybrid electric vehicles (HEVs) will realise nearly zero emission transportation. The widespread usage of EVs and HEVs could significantly reduce air pollution, improve urban environment and increase national energy security and energy independence.
Linkage Infrastructure Awards

*Enhancing Australia's Terahertz Infrastructure*

Funded: 2006  
Total Funding: $147,000  
Project ID: LE0050580  

Sustainable Energy Research and Development Fund  
New South Wales State Government & CSIRO Flagship

*Nanofabrication facilities for processing of novel multilayer materials*

<table>
<thead>
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<th>2005</th>
<th>2006</th>
<th>2007</th>
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Project manager: C. Zhang

To fabricate and measure power generation and cooling effects in a new, highly efficient, type of thermionic device which incorporates energy filters for electronic transport in the form of arrays of quantum dots. The proposed device will incorporate the best features of both multilayer and vacuum thermionic technologies by allowing contact between the hot and cold areas of the device only via arrays of quantum dots. Individual dots in the array will be separated from each other by vacuum or suitably insulating material.
URC Small Grants & ARC Near-Miss Grants

Non-equilibrium superconductivity and quasi-particle dynamics of superconducting materials under terahertz radiation (DP near miss)

Amount funded: $10,000
Chief Investigator: M. J. Qin

Development of giant magnetocaloric materials for refrigeration applications (DP near miss)

Amount funded: $10,000
Chief Investigator: R. Zeng, T. M. Silver, S. Y. Ding

Novel ferroelectric magnetic materials for multi-functional applications

Amount funded: $14,500
Chief Investigator: X. L. Wang

Stronger pinning and larger currents for the second generation of superconducting wires based on thin film technology

Amount funded: $10,000
Chief Investigator: A. V. Pan

Preparation and characterisation of functional semiconductor nanowires

Amount funded: $7,500
Chief Investigator: G. X. Wang

Optimized LiFePO4 using conducting polymers for rechargeable lithium-ion batteries

Amount funded: $8,500
Chief Investigator: J. Wang, J. Chen

Optical readout of silicon: phosphorous electronic states for quantum computation

Amount funded: $14,500
Chief Investigator: R. A. Lewis

University of Wollongong

University Research Council, ISEM Performance Indicator & Management

Year funded: 2006
Amount funded: $125,000
The impact of Nanomaterials on lithium rechargeable batteries, (invited) H. K. Liu (chairperson of a session of “Elaboration and characterisation”)

In this paper we report on the impact of nanomaterials on lithium rechargeable battery performances. Nanotubes (single wall carbon nanotube and multi wall carbon nanotube, NiO and WS₂), nano-intermetallic alloys (Cu₆Sn₅, Sn/SnSb and Sn/SnNi), nano-oxides (NiO, CoO, SnO₂ and Co₃O₄), nano-composites (C-LiFePO₄, Si-C, Si-MCMB (mesocarbon microbeads), Si-TiC, Si-PPY (polypyrrole) and MWNT(multiwalled nanotubes)/Sn/SnNi), as well as other nanoparticles (TiO₂, SiO₂ and Al₂O₃) have been used in lithium rechargeable batteries in our studies. “Free-standing” single wall carbon nanotube (SWNT) papers produced without any binder, and metal substrate shows a capacity slightly lower than that of the conventional electrode. Carbon-coated Si nanocomposites produced by a spray-pyrolysis technique can reversibly store lithium with a high capacity of 1489 mAh/g and high coulombic efficiency above 99.5%, even after 20 cycles. Nanosize 10 wt% TiO₂ increased the ionic conductivity of PEO-LiClO₄ polymer electrolyte by a factor of 2 at room temperature and at elevated temperature.

Nanocomposite materials for use in lithium rechargeable batteries, (invited) H. K. Liu (co-chairperson for session 5 “Lithium-ion batteries”)

To meet the challenge of global warming, a new generation of lithium rechargeable batteries with excellent safety, reliability and cycling life is needed, i.e. not only for applications in consumer electronics but especially for clean energy storage and use in hybrid electric vehicles and aerospace. Nanomaterials and nanotechnologies are playing important roles for next generation lithium rechargeable batteries. In this work, nano-composites including Si-C, C-LiFePO₄, and MWNT (multiwalled nanotubes)/Sn/SnNi as electrode materials in the lithium batteries are presented. Nanostructured Si-C composite prepared by dispersing nanocrystalline Si in carbon aerogel and subsequent carbonization exhibits a reversible lithium storage capacity of 1450 mAh/g when used as anodes in lithium-ion cells. C-LiFePO₄ prepared by a carbon aerogel synthesis process exhibit high capacity and stable cyclability. The MWNT-Sn and MWNT-SnNi anodes have demonstrated a high first discharge capacity (570 and 512 mAh/g for MWNT-Sn and MWNT-SnNi anodes, respectively), high charge/discharge efficiency in the first cycle (77.5% and 84.1% for MWNT-Sn and MWNT-SnNi anodes, respectively), and good cyclability (0.99 loss%/cycle for MWNT/SnNi anode). It is found that the nano-composites investigated improve the electrochemical performances of the lithium cells.

High Performance nano-scale doped MgB₂ (invited) S. X. Dou

Unified mechanisms for the enhancement of electromagnetic properties of MgB₂ by nano-scale doping, (invited) S. X. Dou


YBa₂Cu₃O₇₋δ high temperature superconductors (YBCO), as well as the layered manganite La₂/3Sr₁/3MnO₃ (LSMO) are layered metallic systems where the interlayer current transport occurs via sequential tunnelling of charge carriers. We present in this paper experimental results of magneto-transport studies carried out on YBa₂Cu₃O₇₋δ/La₂/3Sr₁/3MnO₃/YBa₂Cu₃O₇₋δ (YBCO/LSMO/YBCO) thin film multilayers. These heterostructures
were grown on SrTiO3 (STO) substrates by pulsed laser deposition. The close lattice match among the constituent layers of the perovskite YBCO/LSMO/YBCO and the substrate facilitates epitaxial film growth, thus minimizing strong spin-flip scattering at the interface. The temperature dependence of the resistance for different bias currents shows that these heterostructures are clearly influenced by both the insulator-to-metal transition of the LSMO layers at 330 K and the stripe fluctuations in the conductivity of the YBCO layers at the onset of electronic inhomogeneity at ~ 240 K. The samples show a drop between 19 % and 22 % in the resistance for the c-axis tunnelling currents varying from I = 0.05 to 1.0 mA at the critical temperature T ~ 240 K. This behaviour could be related to the opening of a pseudogap. The investigation of these promising hybrid structures is aimed at understanding the science of new spin-based devices.

Spin Valve Behaviour and Spin Polarised Transport in YBa2Cu3O7-δ/La2/3Sr1/3MnO3/YBa2Cu3O7-δ Thin Film Multilayers, G. A. Alvarez, X. L. Wang, D. Q. Shi, and S. X. Dou

Anisotropic YBa2Cu3O7-δ high temperature superconductors (YBCO), as well as the layered manganite La2/3Sr1/3MnO3 (LSMO) are layered metallic systems where the interlayer current transport occurs via sequential tunnelling of charge carriers. We present here experimental results of interlayer spin polarized transport studies carried out on YBa2Cu3O7-δ/La2/3Sr1/3MnO3/YBa2Cu3O7-δ thin film multilayers. The tunnelling of spin polarized charge carriers between the YBCO layers through LSMO leads to a novel spin valve effects at high temperatures. Our samples showed large magneto-resistance with a sharp switching between the high and low resistance states, which we assume corresponds to antiparallel and parallel alignment of the moments of these hybrid structures. The investigation of these promising hybrid structures is aimed at understanding the science of the new spin-based devices, laying the foundation for a new generation of ultra-fast, non-volatile electronics.

Asia-Pacific Symposium on Applied Electromagnetics and Mechanics (21st July 2006, University of Technology, Sydney Australia)

Development of superconductors for applications in electrical devices, (invited) S. X. Dou

Applied Superconductivity Conference (28-31 August 2006, Seattle, USA)

Magnetic field processing to enhance critical current density of CNT doped MgB2, (invited) S. X. Dou

Development of advanced MgB2 conductors with nano-scale doping, S. X. Dou

Study of Oxygen incorporation in PLD MgB2 films by Rutherford backscattering spectroscopy, Y. Zhao, M. Ionescu, S. X. Dou, and H. K. Liu

The Rutherford backscattering (RBS) method has been employed to study the incorporation of oxygen into MgB2 films during their fabrication by pulsed-laser deposition (PLD). A series of MgB2 thin film samples were analysed, including two films produced in situ on Al2O3-c substrates (with higher Tc and lower Tc) with an on-axis geometry, one film produced in situ with an off-axis geometry, and one film produced ex situ, with a bulk-like Tc. The amount of oxygen detected by RBS, which is stable in the form of MgO, appears to be correlated with the Tc of the films, the higher the Tc the lower the oxygen content. The superconducting properties of the thin films are discussed in the context of the RBS results.


Control of nano-structures to enhance energy materials performance properties, (invited) S. X. Dou

17th National Congress of Australian Institute of Physics, (8 December 2006, Brisbane QLD Australia)

Development of advanced MgB2 superconductor by nano-scale doping, (plenary) S. X. Dou
Australian-Chinese Scientists Bilateral Congress, (13 August 2006 University of New South Wales, Sydney Australia)
**Nano-structured materials for energy applications**, (invited) S. X. Dou

2006 Beijing International Materials Week (27 June 2006 Beijing, China)
**Nano-scale doping to enhance the electromagnetic properties of MgB₂ wires**, (invited) S. X. Dou

**Deposition of MgB₂ thin films on Nb substrates using an in situ annealing PLD Method**, Y. Zhao, Y. Wu, S. X. Dou, T. Tajima, and O. S. Romanenko

MgB₂ thin films have been coated on Nb substrates without any buffer layers. An in situ pulsed laser deposition (PLD) method was employed to accomplish the coating. The interface between films and substrates has been characterized by scanning electron microscopy (SEM). Surface impedance has been measured for the MgB₂ films on Nb substrates. The results were discussed with regard to the potential large scale applications in superconducting RF cavities.

International Conference on Optical and Optoelectronic Properties of Materials and Applications (15-22 July 2006, Darwin, Australia)

We calculate the electron density response function of electron-hole multilayer systems in the presence of spin-orbit interaction modelled by Rashba terms. It is found that the spin-orbit coupling leads to a redistribution of the absorption spectral weight between the particle-hole excitation and the plasmon excitation. The interplay of Coulomb interactions and spin-orbit interaction resulted in a suppression or enhancement of the optical absorption due to plasmons. Our result indicates that the spin-orbit coupling can serve as a tuning mechanism for optical absorption in spintronics systems.

Terahertz imaging: materials and methods, S. Hargreaves and R. A. Lewis

Terahertz (THz) imaging is rapidly developing. We present two new methods, based respectively on (a) a broadband thermal source (globar) and (b) a coherent, monochromatic source (optically-pumped THz laser). A room-temperature detector (Golay cell) is employed. Image quality is similar to that reported by others using more complex sources (quantum cascade lasers) and detectors (superconducting tunnelling junctions).

The International Conference on Superlattices, Nano-Structures and Nano-Devices (30 July – 4 August, 2006, Istanbul, Turkey)
**Spin Josephson effect in spintronic nanostructures**, Z. S. Ma, W. Xu, and C. Zhang

The problem of spin current across a ferromagnetic/normal metal/ferromagnetic junction is formulated. It is shown that the spin current is controlled by the phase difference across the junction.

**Negative long wavelength dielectric constant in semiconductor QWs**, S. H. Pilehrood, F. Gao, Z. S. Ma, W. Xu, and C. Zhang

In this work we present an analytical and numerical result of the dielectric function of electronic systems with Rashba spin-orbit interaction. By solving the quantum equation of motion for the electron density matrix, we obtained the dielectric function in the mean-field approximation. It is shown that when the momentum transfer $q$ for an electronic transition is smaller than a critical value characterized by the spin-orbit interaction, the static dielectric function increases with $q$, indicating on-set of a new collective state.
The Joint 31st International Conference on Infrared and Millimeter Waves and 14th International Conference on Terahertz Electronics (18-22 September 2006, Shanghai, China)

**Terahertz absorption in spintronic superlattices**, C. Zhang (session chair), F. Gao, C. H. Yang

In this work we present a theoretical investigation of optical absorption in a spintronic superlattice. It is shown that the Rashba spin-orbit interaction can be used to control the characteristics of the absorption. Our results suggest possible experiments to detect such tuneable absorption spectra. The underlying mechanism is the level splitting and linear energy dispersion; both are the consequences of spin-orbit interaction. The proposed absorption properties can be useful in developing spintronic devices in the terahertz regime.


We have observed THz emission from single and double-layer HgCdTe (MCT) films epitaxially grown on CdZnTe substrates photo excited by femto-second laser pulses. The emitted THz radiation was electro-optically detected in reflection-mode at the 45° specular direction. There is a dramatic variation in the emitted signal level from the double-layer samples, whereas the signal level from the single-layer ones shows a relatively constant variation with composition and/or geometry. For the double-layer samples, the highest peak amplitude recorded is 1/5th of that of the best InAs emitter, analogous to double that of a standard ZnTe emitter, and shows promise for further enhancement.

**THz Waveguides: The Evolution**, R. Mendis (invited keynote)

The development of waveguides is a key element in the technical maturity of the THz field. Suitably designed waveguides can provide innovative solutions for the most fundamental problems of THz energy transfer to the more advanced problems of THz spectroscopy. This presentation will give an overview of the chronological development of THz waveguides, starting from the initial time-domain experiments to the present state-of-the-art, highlighting breakthroughs. Experimental results obtained through waveguide characterization by THz time-domain spectroscopy will be presented and compared to well-known theoretical models, looking at issues related to energy coupling, attenuation, and dispersion, as well as single and multi-mode propagation.

The 3rd International Symposium on Ultrafast Phenomena and Terahertz Waves (25-27 October, 2006, Nanjing, China)

**Two-colour terahertz emission in spintronic materials**, (plenary) C. Zhang

The 3rd International Symposium on Ultrafast Phenomena and Terahertz Waves (25-27 October, 2006, Nanjing, China)

**Two-colour terahertz emission in spintronic materials**, (plenary) C. Zhang

International Conference on Nanoscience and Nanotechnology (ICONN 2006) (3-7 July, 2006) Brisbane, Queensland, Australia

*Chair and co-chair at Symposium C: Nanoelectronics, Spintronics, Nano-Magnetics, Quantum computing, ICCON 2006 (X. L. Wang)*

**Materials for Spintronics**, (oral) X. L. Wang

Korean Applied Superconductivity Conference (July 2006), Korea

**Lastest results on the flux pinning enhancement in MgB2 and multifunctionality in two dimensional cobalt-based compounds**, (invited talk) X. L. Wang
Honorary Professorship in Overseas Institutes

S. X. Dou, Shanghai University, Shanghai, China

S. X. Dou, Beijing University of Science and Technology, Beijing, China

H. K. Liu, Shanghai University, Shanghai, China

C. Zhang, Shanghai Institute of Microsystems and Information Technology, Chinese Academy of Sciences, Shanghai, China

C. Zhang, Tianjin University, Tianjin, China

C. Zhang, Xi’an Institute of Optics and Precise Mechanics, Chinese Academy of Sciences, Xi’an, China

C. Zhang, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei, China
Invited Presentations / Seminars at Other Institutions

S. X. Dou:

29th June 2006, Invited talk, “Development of high performance MgB_2 wires at ISEM” at Institute of Electrical Engineering, Chinese Academy, Beijing, China

6th July 2006, Beijing University of Science and Technology, Invited lecture for a special series of forum by well-known materials scientists from around the world, “Progress in superconducting and electronic materials at ISEM. S. X. Dou was awarded as Honorary Guest Professor at this university

16th July 2006, Invited talk, “Critical current density and upper critical field of nano-doped MgB_2”, at the Institute of Physics, Chinese Academy of Sciences, Beijing, China


29th Sept. 2006, Invited lecture, “Unified mechanism for enhancement in electromagnetic properties of MgB_2 by nano-doping”, at University of Tokyo, Tokyo Japan

17th Oct, 2006, Jiaotong Univ, Shanghai, China, “Unified mechanisms for the enhancement of electromagnetic properties of MgB_2 by nano-scale doping.”

19th Oct 2006, Invited talk, “Critical current density and upper critical field in MgB_2”, at Shanghai University, Shanghai, China

20th Oct 2006, Invited talk, “Development of nanostructured materials for electrodes in Li-ion battery”, at Fudan University, Shanghai, China

23rd Oct 2006, Invited talk, “Introduction to programs at ISEM”, at Korean Atomic Energy Research Institute, Deajun, Korea

C. Zhang

23rd Nov, Invited talk, “Nano thermionics”, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei, China

30th Nov, Invited talk, “Thermionics and thermoelectrics in nanomaterials”, Karlsruhe Centre for Nanotechnology, Karlsruhe, Germany

X. L. Wang

July 2006, Invited talk “Enhancement of flux pinning in MgB_2 superconductors”, at Korea Insitute of Machinery and Materials (KIMM), Korea

G. X. Wang

April 2006, Invited talk, “Semiconductor nanowires for sensor applications” at Andong National University, Korea

April 2006, Invited talk, “Nanostructured building blocks for functional nanoscale devices and systems” at Korea Institute of Machinery and Materials (KIMM), Korea

July 2006, Invited talk, “Nanosize anode materials for lithium-ion batteries” at Fudan University, Shanghai, China

July 2006, Invited talk, “Electrode materials for lithium-ion battery application” at Jiangsu University, Zhengjiang, China
<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Institute</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>11(^{th}) Jan 06</td>
<td>Professor Jung-Ho Ahn</td>
<td>Department of Engineering, Andong National University, Korea</td>
<td>Materials Science and Engineering, Ohio State University, USA&lt;br&gt;Part I – Ni-Zr-Ti-Si-Sn/Cu metallic glass composites prepared by dynamic magnetic compaction</td>
</tr>
<tr>
<td>2(^{nd}) Feb 06</td>
<td>Professor Edward Collings</td>
<td>Laboratories for Applied Superconductivity and Magnetism, Department of Materials Science and Engineering, Ohio State University, USA</td>
<td>Development of magnesium diboride coils and magnets</td>
</tr>
<tr>
<td>10(^{th}) Feb 06</td>
<td>Dr Mike Miller</td>
<td>Metals and Ceramics Division, Oak Ridge National Laboratory, USA</td>
<td>Atomic Scale Micro-structural Characterisation with the Local Electrode Atom Probe</td>
</tr>
<tr>
<td>15(^{th}) Feb 06</td>
<td>Professor Tom Johansen</td>
<td>Department of Physics, University of Oslo, Norway</td>
<td>Magneto-optical and Thermal Imaging of Patterned Superconductors</td>
</tr>
<tr>
<td>15(^{th}) Feb 06</td>
<td>Dr Oleg Mukhanov</td>
<td>Hypres Inc, New York, USA</td>
<td>Ultra-low Heat Leak Superconducting Leads for Cryoelectronic Applications</td>
</tr>
<tr>
<td>17(^{th}) Feb 06</td>
<td>Dr K Togano</td>
<td>National Institute for Materials Science, Japan</td>
<td>An approach of interface diffusion process for fabrication of magnesium diboride</td>
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<tr>
<td>21(^{st}) Feb 06</td>
<td>Dr Hideo Kimura</td>
<td>Piezo Crystals Group, National Institute for Materials Science, Japan</td>
<td>Crystal Growth Activity in NIMS</td>
</tr>
<tr>
<td>8(^{th}) Mar 06</td>
<td>Dr Alexander Kordyuk</td>
<td>Institute for Metal Physics, National Academy of Science, Kiev, Ukraine, and Institute for Solid State and Material Research (IFW), Dresden, Germany</td>
<td>Solving the HTSC puzzle by Angle Resolved Photoemission (ARPES) Simplicity versus Complexity</td>
</tr>
<tr>
<td>16(^{th}) Mar 06</td>
<td>Dr Alexander Kordyuk</td>
<td>Institute for Metal Physics, National Academy of Science, Kiev, Ukraine, and Institute for Solid State and Material Research (IFW), Dresden, Germany</td>
<td>Correlation of single particle excitation spectrum with transport properties of high-Tc cuprates</td>
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<tr>
<td>21(^{st}) Mar 06</td>
<td>Dr Gavin Conibeer, Dr Dirk Konig, Chu-Wei Jiang</td>
<td>Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, School of Photovoltaic Engineering, University of New South Wales</td>
<td>Application of selective energy contacts to thermoelectric cells</td>
</tr>
<tr>
<td>10(^{th}) Apr 06</td>
<td>Professor Peter Notten</td>
<td>Electrochemical Energy Storage, Eindhoven University of Technology, and Philips Research Laboratories, Netherlands</td>
<td>Electrochemical Energy Storage: from materials research to battery modelling</td>
</tr>
<tr>
<td>Date</td>
<td>Name</td>
<td>Institute</td>
<td>Title</td>
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<tr>
<td>26th Apr 06</td>
<td>Professor Hans L. Hartnagel, Dr. Jochen Sigmund</td>
<td>T. University Darmstadt</td>
<td>Non-stoichiometric growth of LTG -GaAs and -GaAsSb for Binary Optical Mixing to generate THz-Signals</td>
</tr>
<tr>
<td>2nd May 06</td>
<td>Dr. Cezary Sydlo</td>
<td>T. University Darmstadt</td>
<td>Design and Technology of THz Antennas at TUD</td>
</tr>
<tr>
<td>29th May 06</td>
<td>Dr Sun Changqing</td>
<td>Nanyang Technological University, Singapore</td>
<td>Bond formation and relaxation at surfaces: theory, experiment, and applications</td>
</tr>
<tr>
<td>28th Jun 06</td>
<td>Professor Hee-Gyoun Lee</td>
<td>Department of Advanced materials and Engineering Korea Polytechnic University</td>
<td>Characteristics of HTS coated conductor and its application for persistent mode magnet</td>
</tr>
<tr>
<td>28th Jul 06</td>
<td>Professor Jun Chen</td>
<td>Institute of New Energy Material Chemistry College, Nankai University, China</td>
<td>Inorganic Nanomaterials for Batteries, Fuel Cells and Solar Cells</td>
</tr>
<tr>
<td>10th Aug 06</td>
<td>Professor K L Yao</td>
<td>Physics Department Huazhong University of Science &amp; Technology, China and University of Melbourne, Australia</td>
<td>Organic Ferromagnets: A New Kind of Magnetic Materials</td>
</tr>
<tr>
<td>16th Aug 06</td>
<td>Prof Gang Chen (Warren &amp; Towneley Rohsenow Professor)</td>
<td>Mechanical Engineering Dept Massachusetts Institute of Technology (MIT) Cambridge, MA, USA</td>
<td>Energy Nanotechnology</td>
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<tr>
<td>18th Oct 06</td>
<td>Professor Koung-An Chao</td>
<td>Department of Physics, Lund University</td>
<td>Temperature related problems in nanoscale systems</td>
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<tr>
<td>1st Nov 06</td>
<td>Prof Xuechu Shen</td>
<td>Chinese Academy of Science Shanghai University</td>
<td>Magneto-Micro-PL Spectroscopy of Single Quantum Dot CdSe</td>
</tr>
<tr>
<td>7th Nov 06</td>
<td>Dr. Ketak Kim</td>
<td>Korea Electrotechnology Research Institute</td>
<td>Carbon Coatings on LiFePO₄</td>
</tr>
<tr>
<td>17th Nov 06</td>
<td>Dr Xiaozhou Liao</td>
<td>School of Aerospace, Mechanical and Mechatronic Engineering University of Sydney</td>
<td>Materials Characterisation using Advanced TEM/STEM Techniques</td>
</tr>
</tbody>
</table>
ISEM facilities contain 9 laboratories with a floor space of approx 420m² comprising modern facilities for processing and characterization of HTS and energy storage materials; materials processing and a full range of materials characterization.

The majority of these facilities were founded through 6 ARC RIEF programs and the Metal Manufactures Ltd Consortium program over the past six years.

The following institutions and Chief Investigators have been involved with the ARC RIEF proposals in the past:

Australian National University  
Dr. M. Das

Australian Nuclear Science & Technology Organisation  
Dr. E. R. Vance

CSIRO  
Dr. N. Saviddes,  
Dr. K. Müller

Curtin University  
Prof. D. Y. Li  
Dr. I. Low

James Cook University  
Prof. J Mazierska

Macquarie University  
A/Prof. E. Goldys

Monash University  
Dr. Y. B. Cheng  
Dr. R. Krishanmurthy

University of Melbourne  
A/Prof. D. N. Jamieson

University of NSW  
Prof. M. Skyllas-Kazacos  
Dr. S. Li  
Dr. R. Ramer  
Prof. S. Campbell

University of Queensland  
Prof. M. G. Lu, Dr. L Wang  
Prof. D. R. Mackinnon

University of Sydney  
A/Prof. S. Ringer, Dr. R.K. Zheng  
Dr. V. Keast, Dr X.Z. Liao

University of Technology, Sydney  
Prof. J. G. Zhu  
Prof. J. Smith

Curtin University  
A/Prof. J. Low

University of West Sydney  
Prof. M. Wilson

**Materials Processing Facilities**

- Freeze Drier, Lyph-Loch 4.5, 4.5l/24h
- Spray Drier, GA-32, ~100g/h
- Spray Drier OPD8 3l/hour
- Attrition Mill, 01-HD, 0-660rpm
- Planetary Mill, pulverisette 5, 0-300rpm agate
- Drawing Bench, 8m, fixed die, 11.5kW
- High energy ring mill
- Ultrasonic spray unit, 10-30μm droplets, 0.1-1 litre/hour
- Bull Block, 22cm diameter
- Rolling mill, 2 x 60mm flat & square rollers, 5cms
- Rolling mill, 2 x 55mm supported rollers, 5cm/s
- Swagging machine, 15-1mm diameter
- Hydraulic press, 10t-100t
- More than 30 various furnaces
- Controlled atmosphere glove boxes
Thin Film Deposition and Structuring Facilities

- Excimer laser, ComPex301, 9W, 10Hz, 248nm
- Thin Films Pulsed-Laser Deposition (PLD) Chamber, 18" With high vacuum system
- Ultra High Vacuum (UHV) PLD chamber equipped with ISD and IBAD (to be completed in 2005).
- UHV chamber (10^{-12} mBar) with multi-target rf magnetron sputtering and multi-pocket electron beam evaporation EBE techniques with direct HV connection to UHV analysis chamber.
- Electron Beam Lithography (EBL) system on the base of SEM (LaB6).
- Optical lithography.

Materials Characterisation

- DTA/TG, Setaram, 18-92, 1750°C
- XRD for Single Crystals
- TEM, J2000FX1, with EDS
- Gas absorption analyser Nova 1000 for BET and pore size analyses
- XRD, M18XHFCu with HT 2000°C camera
- XPS, AES, ISS, UVPS in UHV analysis chamber connected to UHV thin film deposition chamber.
- SEM (LaB6 filament) JEOL, equipped with EDS
- SEM, Stereoscan 440, with EDS and EBSP
- AFM, Nanoscope IIIa
- Particle Size Analyser, Mastersizer S, 0.05-900μm
- XRD, PW1050, 3kW; XRD Texture, PW1078, 3kW
- DSC, TA300,-170°C+600°C

Physical Property Characterisation

- MPMS, 1.5-400K, 0-5T DC field
- PPMS, 4-400K, 0-9T DC field
- Horizontal field superconducting Magnet, 0-8T, 5-300K
- Lock-in Amplifier, SR510; Lock-in Amplifier, SR830DSP, 2 x PAR 5209 Lock-in Amplifier, PAR 124 Lock-in Amplifier
- Magneto Optical Imaging, 2K-300K, up to 0.2 T DC field
- Electromagnet, HSV-4H1, 2T, 100mm pole diameter
- Five power supplies (HP and Keithley) 0-900A
- Cryogenic Temperature Controller, ITC4, 0-500K
- SR560 low-noise preamplifier
- Pacific Power 3120 AMXoc current source, 12 kVA
- Spectrometers, Bomem DA3 - fast scan interferometer, Polytec FIR 25 (modified) - slow scan interferometer, Beckman FS 720 - slow scan interferometer, SPEX 1402 double grating 1 m instrument, SPEX 1704 single grating 1 m instrument, 2xSPEX 1870 single grating 0.5 m instruments
- Ballantine 1620 transconductance amplifier (up to 100A)
- Magnets, Oxford Instruments superconducting (0-7T), 2x4 inch iron-cored, Rawson-Lush gaussmeter
- Cantilever (torque force) magnetometer
- Various multimeters, HP and Keithley, including a nano-voltmeter
- VSM, Maglab, 2-400K, 0-12T DC field CTI 8001/8300 cryocooler
- Thermal conductivity measurement
- Function Generator, DSC340; Digital Oscilloscope, TDS320
- Digital Teslamanter, DTN-132, with Hall Probe; Fluxmeter, 916
- 2 x He Recovery System, including liquefier – 40 litres/day
- Eddy current generator
- Electromagnet, 3473-70, 2T, 150mm pole diameter, Rawson-Lush Gaussmeter
- Detectors, 4xInfrared Laboratories bolometers, Infrared Laboratories Ga-doped Ge photoconductor, N. Coast Scient. Corp Ge photoconductor, Photomultiplier with GaAs photo-cathode
- Cryostats, A number of L He with optical access, L N cryostats, 60 L He storage, 30 L He storage, 60 L L He storage, 50 L N storage, 2x30 L L N storage, 25 L L N storage, A system for recovering and compressing He gas is in place
- Leak detector Vacuum system

Electro-Chemical Property Characterisation

- Cyclic Voltammograph, BAS CV-27
- Impedance Analyser, M6310
- Temperature Controlled Water Bath, F10-MF
- Four Channels Data Collection System, MacLab/4e
- ICP-OES, Vista MPX simultaneous axial spectrometer, 167-785nm range 0.009nm resolution 200nm
- Scanning Potentiostat, M326; Potentiostat, M363
- Power Supply, DCS 20-50, 0-20V, 0-50A

Electro-Chemical Property Characterisation (continued)

- Eight Channels Data Collection System, MacLab/8
- Controlled Atmosphere System (Glove Box), OP7
- Amplifiers, PAR 124A Lock-in, 2xPAR 5209 Lock-in, Stanford Research SR510
- CHI 660B Electrochemical Workstation
- Arbin MSTAT8000 Electrochemical Workstation
- Automatic PCT Measuring System

Ultra high vacuum (UHV) multi-purpose pulsed laser deposition (PLD) chamber with an incorporated ion gun for ion-beam assisted deposition (IBAD) and a possibility to carry out inclined substrate deposition (ISD) process. It is also equipped with a multi-target holder and large rotating substrate/sample heater/holder. The control instrument rack for automated control of the PLD chamber is situated next to it.

- Multipurpose Wire Bonder for Micro-Devices
- UV/Visible light spectrometer
- Veeco Profilometer
ICP-OES, Vista Simultaneous Axial Spectrometer

Setaram high-temperature DTA/TGA instrument

Magnetic Property Measurement System
4K-300K, 0-5T

Electron Beam Evaporation Facility

High-resolution JEOL SEM/EBL system

Glove box for Creating Oxygen and Moisture free Environment


*IF = Impact Factor*


20. Z. G. Huang, Z. P. Guo, D. Wexler, K. Konstantinov, and H. K. Liu, “Thermal stability and hydrogen storage property of Mg_{1.9}Cu_{0.1}Ni_{x} (x = 1.8, 1.9, 2.0 and 2.1) alloys”, *Journal of Alloys and Compounds* 426, 335-340 (2006) (IF: 1.562).


64. P. Z. Shen, Y. D. Huang, L. Liu, D. Z. Jia, and Z. P. Guo, “Synthesis and electrochemical performance of LiCr$_{x}$Mn$_{3-x}$O$_4$ (x = 0, 0.02, 0.05, 0.08, 0.10) powders by ultrasonic co-precipitation”, Journal of Solid State Electrochemistry 10, 929 (2006) (IF: 1.158).


Summary:
Total of 97 papers
52 papers in journals with IF greater than 2 (54%)
19 papers in journals with IF greater than 4 (20%)

Conference Papers


### ARC Large/Discovery Scheme Grants

<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Project Description</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. X. Dou, J. Horvat</td>
<td>First principles for development of high temperature superconducting wires</td>
<td>$210,000</td>
</tr>
<tr>
<td>S. X. Dou, M. J. Qin</td>
<td>Control of nano-structure for enhancing the performance of magnesium diboride superconductor by chemical doping</td>
<td>$105,000</td>
</tr>
<tr>
<td>X. L. Wang</td>
<td>Exploration for new materials for spintronics</td>
<td>$210,967</td>
</tr>
<tr>
<td>R. A. Lewis</td>
<td>High Efficiency Terahertz Emitters</td>
<td>$123,000</td>
</tr>
<tr>
<td>H. K. Liu, Z. P. Guo</td>
<td>Hydrogen storage materials for energy conversion applications</td>
<td>$85,000</td>
</tr>
<tr>
<td>A. V. Pan</td>
<td>Development of height-temperature superconducting coated conductors by pulsed-laser deposition for future long-length applications</td>
<td>$70,000</td>
</tr>
<tr>
<td>A. V. Pan, S. Zhou, Y. Genenko, T. H. Johansen</td>
<td>Development of new technology for coated conductors able to carry &quot;over-critical&quot; current densities</td>
<td>$115,000</td>
</tr>
<tr>
<td>G. X. Wang, K. Konstantinov, J. Ahn, X. Q. Yang, Z. Xiao</td>
<td>Synthesis of nanowires and application as nanosensors for chemical and biological detections</td>
<td>$78,000</td>
</tr>
<tr>
<td>C. Zhang, R. A. Lewis, X. Zhang, R. E. M. Vikers</td>
<td>Non-linear dynamics in electronic systems and devices under intense terahertz radiation</td>
<td>$170,000</td>
</tr>
<tr>
<td>D. Q. Shi</td>
<td>Development of conductive buffer layers for RABiTS-based coated conductors</td>
<td>$80,000</td>
</tr>
<tr>
<td>Y. Zhao, M. Ionescu, J. Du, E. W. Collings</td>
<td>Superconducting MgB₂ thin films and structures for electronic devices and telecommunication applications</td>
<td>$125,000</td>
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**Total Funding: $1,501,967**

### ARC Centre of Excellence Grants

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<tr>
<th>Name(s)</th>
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<th>Funding</th>
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</thead>
<tbody>
<tr>
<td>H. K. Liu</td>
<td>Nano-materials for energy storage</td>
<td>$230,000</td>
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</table>

**Sub-total: $1,731,967**
**Strategic Partnerships with Industry (SPIRT) Scheme - Linkage & Linkage APAI**

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Project Description</th>
<th>Funding Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. X. Dou, A. V. Pan</td>
<td>Novel electric field induced coupling technique for liquid-phase heteroepitaxial growth of carbon thin films with diamond-like structure</td>
<td>$24,148</td>
</tr>
<tr>
<td>H. K. Liu, J. Wang, G. X. Wang</td>
<td>Lithium/sulphur rechargeable batteries for power applications</td>
<td>$75,000</td>
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<tr>
<td>G. X. Wang</td>
<td>Large-scale rechargeable lithium battery for power storage and electric vehicle applications</td>
<td>$110,000</td>
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<tr>
<td>S. X. Dou, D. Shi, M. J. Qin, T. Beales, C. J. Hawley</td>
<td>Development of high performance second generation superconductors</td>
<td>$115,000</td>
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</table>

**Linkage International Awards**

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Project Description</th>
<th>Funding Amount</th>
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</thead>
<tbody>
<tr>
<td>S. X. Dou, A. V. Pan</td>
<td>Magneto-optical imaging of super-current flow in superconducting tapes and wire</td>
<td>$11,160</td>
</tr>
<tr>
<td>M. J. Qin, S. Ding</td>
<td>Molecular dynamic simulation and experimental study on the mechanisms of high critical current density in superconductors</td>
<td>$11,300</td>
</tr>
<tr>
<td>C. Zhang, D. Abbott, X. C. Zhang</td>
<td>Photon induced nonlinear absorption and transport in semiconductor nanostructures</td>
<td>$13,000</td>
</tr>
<tr>
<td>H. K. Liu; A. V. Pan</td>
<td>The role of nano-structures for the super-current flow and limitation in high-temperature superconducting films and multi-layers</td>
<td>$18,340</td>
</tr>
<tr>
<td>C. Zhang, D. Abbott, X. C. Zhang</td>
<td>Terahertz optoelectronics based on spintronics materials</td>
<td>$12,000</td>
</tr>
<tr>
<td>G. Wang, J. Horvat, K. K. Konstantinov, J. Z. Wang, Y. Kim</td>
<td>Nanostructured materials for development of advanced lithium energy storage systems</td>
<td>$10,000</td>
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</table>

**Linkage Infrastructure**

<table>
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<tr>
<th>Researchers</th>
<th>Project Description</th>
<th>Funding Amount</th>
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**Total Funding Amount:** $495,009

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**Linkage Infrastructure**

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<th>Researchers</th>
<th>Project Description</th>
<th>Funding Amount</th>
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**Total Funding Amount:** $147,000
### Research Infrastructure Block Grants

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<tr>
<th>Name</th>
<th>Project Description</th>
<th>Amount</th>
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<tbody>
<tr>
<td>J. Horvat, R. A. Lewis, W. Li, J. Norrish, A. Rozenfeld, G. Spinks</td>
<td>Multipurpose wire bonder for micro-devices</td>
<td>$33,000</td>
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<tr>
<td>S. X. Dou</td>
<td>Laboratory Management Fellow</td>
<td>$74,000</td>
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**Total:** $107,000

### SERDF Grants

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<th>Name</th>
<th>Project Description</th>
<th>Amount</th>
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<tbody>
<tr>
<td>C. Zhang</td>
<td>Nanofabrication facilities for processing of novel multilayer materials</td>
<td>$96,000</td>
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**Total:** $96,000

### Small Grants & Indicative Near Miss Grants

<table>
<thead>
<tr>
<th>Name</th>
<th>Project Description</th>
<th>Amount</th>
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<tbody>
<tr>
<td>G. Alvarez, C. Hawley, X. Wang</td>
<td>Quantum effects and electronic noise in single electron devices</td>
<td>$10,000</td>
</tr>
<tr>
<td>R. E. M. Vickers, P. Fisher</td>
<td>A precise method for determining the amount of phosphorus atoms doped into silicon</td>
<td>$11,000</td>
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**Total:** $31,000

### Australian Institute of Nuclear Science & Engineering

<table>
<thead>
<tr>
<th>Name</th>
<th>Project Description</th>
<th>Amount</th>
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<tbody>
<tr>
<td>P. Fisher</td>
<td>An optical spectroscopic method for determining the concentration of phosphorus introduced into silicon by neutron transmutation</td>
<td>$10,000</td>
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**Total:** $10,000

### Industry Grants

<table>
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<tr>
<th>Company</th>
<th>Amount</th>
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<tr>
<td>Guangzhou Delong</td>
<td>$15,000</td>
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<tr>
<td>Hyper Tech Research Inc</td>
<td>$30,000</td>
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<tr>
<td>SOPO Ltd.</td>
<td>$22,000</td>
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<tr>
<td>Alphatech International Ltd</td>
<td>$5,000</td>
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**Total:** $72,000

### University of Wollongong Support

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<tr>
<td>ISEM Performance Indicators</td>
<td>$87,429</td>
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<tr>
<td>Faculty of Engineering funding</td>
<td>$20,000</td>
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<tr>
<td>URC contribution</td>
<td>$125,000</td>
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<tr>
<td>Postgraduate student maintenance funds</td>
<td>$41,250</td>
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<tr>
<td>Scholarships</td>
<td>$300,000</td>
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</tbody>
</table>

**Total:** $573,679

### TOTAL 2006 funding

| Total amount | $3,339,455 |

81
Applied Superconductivity

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