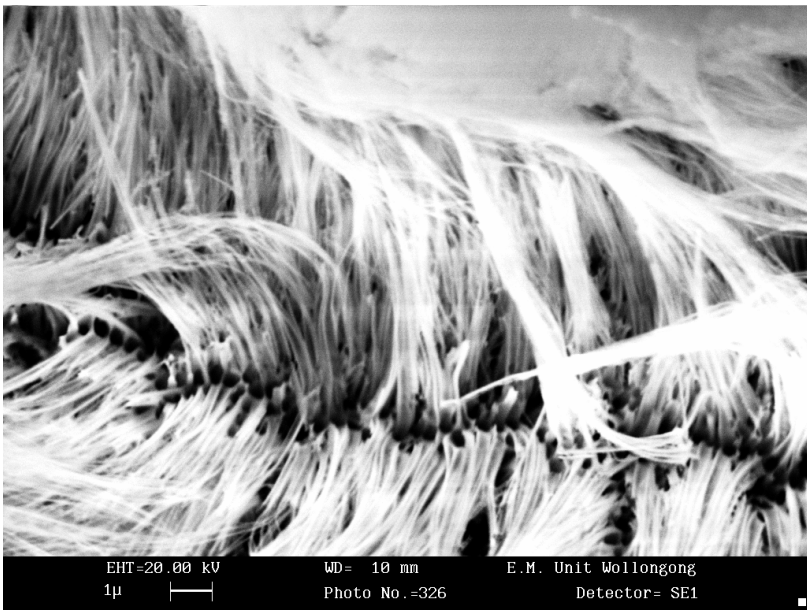
# Institute for Superconducting & Electronic Materials




# Annual Report 2003

University of Wollongong

# Contents



Cover picture:

Nickel-Phosphorous nanowires formed by electroless deposition within an anodic aluminium oxide (AAO) template

Photograph by Scott Needham – ISEM Postgraduate Student

# ISEM Postgraduate Student Awards

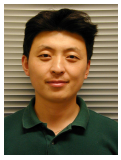
Each year ISEM selects a number of outstanding students and in recognition of their research efforts, these students are presented with a Certificate to mark their achievements, together with a cash prize.

## Postgraduate Student Excellence Awards

2002

S. Keshavarzi

2003



Yue Zhao

## Postgraduate Student Merit Awards

2002

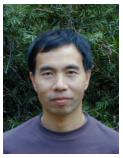
S. Bewlay

M. Lindsay

S. Soltanian

S. Zhou

2003



Q.W. Yao

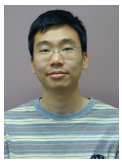
M. Roussel

Y. Chen

S. Bewlay

## Best Postgraduate published paper Award 2003

S. Soltanian



W.K. Yeoh

## Mission Statement

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.

Professor SX Dou
Director
e-mail: shi_dou@uow.edu.au

Dr M Ionescu
Assistant Director
e-mail: mionescu@uow.edu.au

Mrs BM Allen
Administration Officer
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Telephone: 61 + 2 4221 5730
Facsimile: 61 + 2 4221 5731
web site: http://www.uow.edu.au/eng/ISEM

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## *Applied Superconductivity*

Dr. J Horvat
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Facsimile: 61 + 2 4221 5731
e-mail: jhorvat@uow.edu.au

## *Spintronic & Electronic Materials*

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Facsimile: 61 + 2 4221 5731
e-mail: xiaolin@uow.edu.au

## *Energy Materials*

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Dr. G.X. Wang
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Facsimile: 61 + 2 4221 5731
e-mail: gwang@uow.edu.au

## *Thin Film Technology*

Dr. M. Ionescu
Telephone: 61 + 2 4221 4729
Facsimile: 61 + 2 4221 5731
e-mail: mionescu@uow.edu.au

Dr A.V.Pan
Telephone: 61 + 2 4221 4729
Facsimile: 61 + 2 4221 5731
e-mail: pan@uow.edu.au

## *Nanostructured Materials*

Dr. K. Konstantinov
Telephone: 61 + 2 4221 5765
Facsimile: 61 + 2 4221 5731
e-mail: kostan@uow.edu.au

## *Terahertz Science, Thermionics & Solid State Physics*

Prof. C. Zhang
Telephone: 61 + 2 4221 3458
Facsimile: 61 + 2 4221 5944
e-mail: chao_zhang@uow.edu.au

# Director's Report

Prof. Shi Xue Dou
PhD, DSc, FTSE
ARC Australian Professorial Fellow

2003 is the 10th year since The Institute for Superconducting and Electronic Materials (ISEM) moved to Wollongong. In this time, ISEM has built an interdisciplinary research capability in energy materials and technology. A single research program on superconductivity in 1994 has evolved into six programs including applied superconductivity, energy storage materials, spintronics, thin film technology, Terahertz and thermionics and nano-materials. These six programs have all been successful in winning either ARC or other source funding. Although diversifying and extending our research program we have not lost research focus on energy materials and technology. Energy is the single most critical factor affecting worldwide prosperity in the coming century. ISEM has focused on the establishment of interdisciplinary research programs in energy materials and technology that underlie solar power, hydrogen energy, fuel cells, batteries, flywheels, electric power transmission and electric vehicles. Nano-materials and nanotechnology will play a key role in these technologies. ISEM's staff profile is of world class, consisting of 20 well established researchers (including 8 ARC fellows) with world-class, well-equipped laboratories and excellent postgraduate student outcomes.

Among our many achievements, nano-scale particle doping to enhance superconductor performance has received the most attention. A record high upper critical field of 37 Tesla has been achieved for nano-particle SiC doped $MgB_2$ wire. The critical current density in magnetic fields for nano-particle doped $MgB_2$ increased by more than an order of magnitude, compared to the best results reported in literature. This is one of the most important advances since the discovery of superconductivity in this material and will have an important impact on the development of technological superconductors. Our team has used this discovery to develop superconductor wires which can carry one million Amperes per square centimeter at 20K, demonstrating the great potential of this emerging superconductor for various practical applications such as magnets for magnetic resonance imaging (MRI), power cables, motors, energy storage systems, generators, magnetic separators and transformers. This achievement has been verified by leading groups at the National High Magnetic Field Laboratory in Florida, the University of Geneva, Los Alamos National Laboratory, the National Institute of Materials Science in Japan, the University of Wisconsin and Ohio State University. A PCT patent has been filed for the protection of the invention. Due to the significant enhancement in critical current density that can be achieved by nano-scale SiC doping, it is evident that in the future $MgB_2$ wires for large-scale applications will not be competitive without SiC doping.

In 2004 our institute scored its second most successful year in obtaining ARC funding, with 8 grants across all categories, including; 4 Discovery grants, 2 Linkage projects, 1 Linkage Infrastructure, 1 Linkage International, including 2 Australian Post Doctoral (APD) fellowships (A. Pan and Z.P. Guo) and 1 APD (Industry) fellowship (J.Z. Wang), totalling $1,904,450. As a part of the Centre of Excellence, Prof. H.K. Liu was awarded a project grant including an Australian Professorial Fellowship (APF) for five years ($875,874). In the second round of ARC Linkage projects, Drs. B. Richards and M. Ionescu won a grant of $360,000 to develop $TiO_2$ thin films for photovoltaic devices and Dr Richards was awarded an APDI fellowship. This brought our 2004 total ARC funding to $3,140,320 plus industry cash contribution of $387,000, a truly excellent performance. What is more encouraging is that our early career researchers and postgraduate students have displayed tremendous potential for future success. Six of the twelve Chief Investigators from our institute in this round are early career researchers, 50%! Our policy to build a strong team has paid off. I am confident that our current postgraduate students can take up the challenge the former students have laid down.

As usual, our staff remains dynamic. Associate Professor Chao Zhang was promoted to full Professor. Dr. J. Horvat was jointly appointed as a half-time lecturer at both the School of Engineering Physics and ISEM. Drs Z.P. Guo, A. Pan and J.Z. Wang have taken up their ARC fellowships. Dr M. Ionescu accepted an offer from ANSTO in May 2004 after collaborating with this group for 13 years. He has been instrumental in the establishment and growth, in particular in laboratory construction, of our institute. He will remain as an honorary visiting fellow and continue to collaborate with our staff and act co-supervisor for some postgraduate students. Professor J.Y. Lee and Professor J.H. Ahn completed their ARC International Professorial Fellowships at ISEM in 2003 and early 2004 respectively. Drs Z.X. Cheng and S.H. Zhou received JSPS fellowships from the National Institute of Materials Science in Japan.

We have supported a number of visiting researchers and internship students, including visiting staff: Prof S.Y. Ding from Nanjing University, Dr. G. Alvarez from Tokyo University of Technology, Dr. H.F. Zhen from National Singapore University, Mr L. Yang from Shenzhen; and internship students: E. Milin, E. Getin, H. Charge, and X. Menard from French universities, and Y.M. Kang, M.S Song and K.T. Kim from Korean Advanced Institute for Science and Technology.

ISEM postgraduate students have made significant progress on their degree programs. D. Marinaro, J. McKinnon and J.Z. Wang were awarded PhD degrees and Z. Zhang and M. Farhoudi were awarded Masters degrees. Yue Zhao won ISEM's postgraduate student excellence award, while S. Bewlay, Y. Chen, M. Roussel and Q.W. Yao won ISEM postgraduate student merit awards in 2003. In order to improve the quality of our publication record, in 2003 we established a new award for the best published postgraduate student paper. The joint winners were S. Soltanian for his Physical Review B paper and W.K. Yeoh for his Applied Physics Letter paper. In 2003 we had a number of successful scholarship applications with S. Needham and M. O'Dwyer receiving APA scholarships, J. Yao an APAI scholarship, O. Scherbakova and G. Peleckis won double scholarship-IPRS and UPA, R. Zhang won a UPA scholarship. We have awarded ISEM scholarships to B. Winton, M. Smith, M. Farhoudi, Z.G. Huang, L.Q. Mai, S.H. Ng, and K. de Silva. We congratulate and welcome all new postgraduate students to the institute and wish them well in their research efforts.

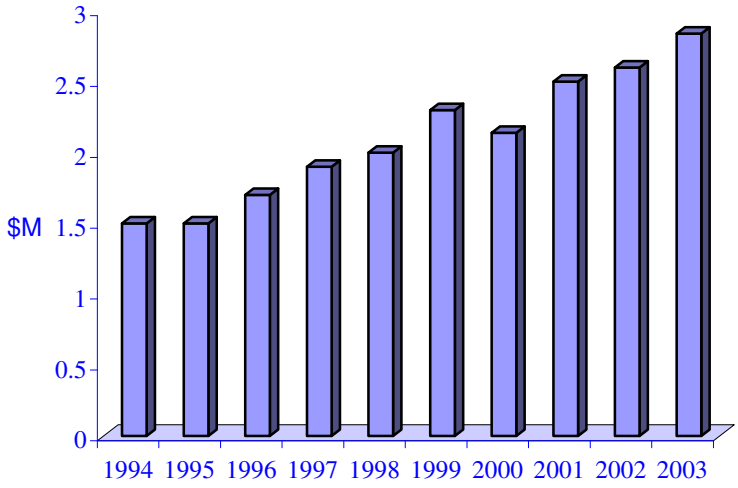
We have made significant progress in laboratory construction. The nano-multilayer fabrication facilities have all been commissioned or ordered. These include Electron Beam Evaporator (EBE) and Magnetron Sputtering units integrated in ultra high vacuum chamber, surface analysis unit for XPS, Auger, UPS, ISS, SAM and IELS and a high performance Jeol SEM with LaB6 gun, EDX and BSC (backscattered detectors) and Electron Beam Lithography (EBL) unit. These facilities were funded through the Systemic Infrastructure Initiative scheme by DIST with total funding of $1.7 million over three years and supported by 13 institutions around Australia. The Physics group at ISEM has built a terahertz radiation facility which can produce ultrashort pulses of light less than 12 femtoseconds. This was funded through an ARC LIEF grant involving the University of Wollongong, Australian National University, University of Technology Sydney and University of New South Wales.

Our strategy over the next few years is to consolidate the extended research programs; enhance postgraduate training; improve our research staff profile and stability; increase our ARC funding success rate; foster industry links; and promote national and international collaboration. We will propose a program on energy materials and technology to apply for the next round for ARC centre of excellence funding. Our numerical target for the next three years is 10 ARC fellows, 20 full time researchers, 40 postgraduate students enrolled, 50% papers published at journals with impact factor greater than 2 and $2m ARC funding per year.

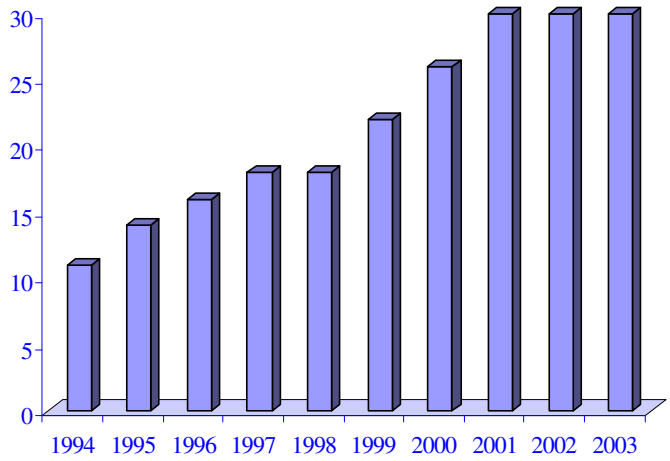
S X Dou

Shi Xue Dou

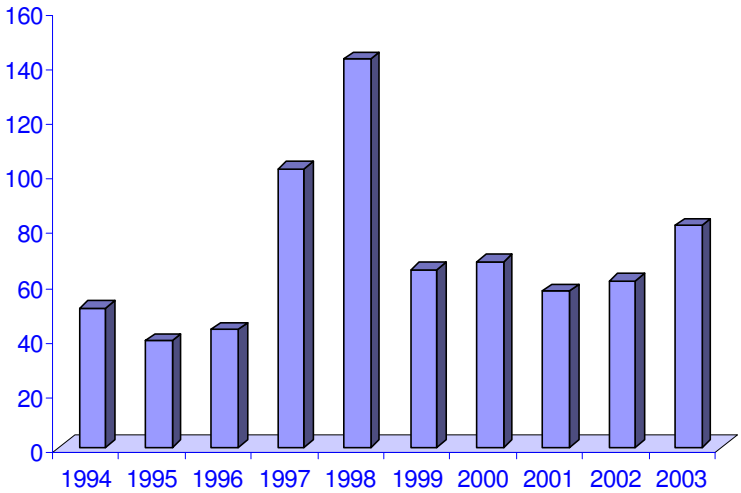
## Research Grant Funds



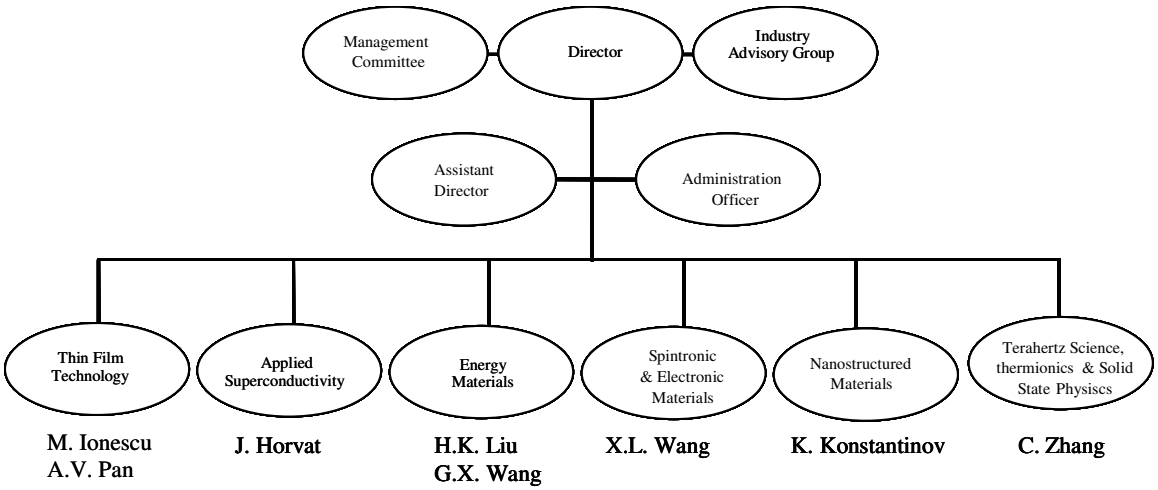

## Postgraduate Student Numbers




## Refereed Publications (DETYA Categories)



# Management




## Management Committee

| | | |
|---|---|---|
| Chairperson: | Prof. M. Sheil | Pro Vice Chancellor, UoW |
| | Prof. S.X. Dou | Director, ISEM |
| | Prof. C. Cook | Dean, Faculty of Engineering, UoW |
| | Prof. H.K. Liu | Research Co-Ordinator, ISEM |
| | Prof. C. Zhang | Research Co-Ordinator, ISEM |
| | Dr. M. Ionescu | Assistant Director, ISEM |

## Industry Advisory Group

| | | |
|---|---|---|
| Dr T. Beales | Manager | Australian Superconductors Ltd, Metal Manufactures Ltd |
| Mr B. Buchtmann | Advanced Syst. Engineer | Email Limited |
| Dr S Dunmead | Vice President for R&D | OM Group, USA |
| Dr. X.F. Gao | General Manager | Lexel Batteries Co. Ltd, Shenzhen, PR China |
| Mr R. Neale | Managing Director | Alphatech International Ltd |
| Mr M. Tamlin | General Manager Marketing | Sons of Gwalia Ltd, Perth |
| Mr A Sheth | Technical Marketing Manager | Sons of Gwalia Ltd, Perth |
| Mr M. Tomsic | Managing Director | Hyper Tech Research Ltd, Ohio, USA, |
| Prof J.S. Wang | President | Taiyi Battery Co. Ltd., Zhuhai, PR China |
| Mr J.F. Wu | Marketing Manager | DLG Battery Co Ltd, Shenzhen, P.R. China |
| Dr. S. Zhong | Managing Director | Guangzhuo Delong Energy Technology, Guangzhuo P.R. China |

# Personnel

## Director

Prof. S.X. Dou, Dipl, PhD, DSc, FTSE

## Assistant Director

Dr M Ionescu, BSc, MSc, PhD

## Senior Program Co-Ordinators

Prof. T. Beales, BSc, PhD MM/UoW Consortium Manager

Prof. H.K.Liu, Dipl. for PGS, APF.

Prof. C. Zhang, BSc, PhD, MA, MPhil, FAIP

Dr. J. Horvat, BSc, PhD

Dr. X.L. Wang, BSc, MSc, PhD, ARC Postdoctoral Fellow

Dr. M. Ionescu, BSc, MSc, PhD

Dr. K. Konstantinov, BSc, MSc, PhD

## ARC Fellows

Prof. J.H. Ahn, Assoc. Professorial Fellow

Prof. S.X. Dou, Dipl, PhD, DSc, FTSE, Australian Professorial Fellow

Dr. Z.P. Guo, BSc, MSc, PhD, Australian Postdoctoral 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 Postdoctoral Fellow

Dr. J. Wang, BSc, MSc, PhD, ARC Postdoctoral Fellow

Dr. X.L. Wang, BSc, MSc, PhD, ARC Postdoctoral Fellow

Prof. J.Y. Lee, ARC International Prof. Fellow

## Research Staff

Dr. Z. Cheng, BSc, MSc, PhD

Dr. M.J. Qin, BSc, MSc, PhD

Dr. T. Silver, BSc, PhD

Dr. R. Zeng, BSc, MSc, PhD

## Academic Staff

Prof. C. Cook, BSc, PhD, FIEAust

Prof. D. Dunne, BSc, PhD, FIEAust

Dr. C. Freeth, MSc, PhD, MAIP

Ass/Prof. R. A. Lewis, BSc (Hons), PhD, FAIP, FRMS

Dr. A.D. Martin, MSc, PhD, MAIP

Dr. R.E.M. Vickers, MSc, PhD, MAIP

Prof. P. Fisher, BSc, PhD

## Visiting Staff

Prof. E.W. Collings, Ohio State University

Prof. H. Liu, Sichuan Uni, PR China

Dr. S. Kennedy, ANSTO

Dr. S. Zhong, Delong Energy Technology, China

Prof. J. Chan, Nankai University, PR China

Dr. G. Alvarez

## Technical Staff

Mr C. Rossi

Mr. R. Kinnell

## Administration Officer

Ms. Babs Allen

# Postgraduate Students

## Current

| PhD | Thesis Title | Supervisors |
|---|---|---|
| S Bewlay | Investigation on Li-Co-Ni System for Lithium Ion Batteries | SX Dou, GX Wang |
| Y Chen | Investigation of Cathode Materials for Li-ion Batteries | HK Liu, GX Wang |
| K. de Silva | Coated conductors | SX Dou, AV Pan |
| ZJ Dou | Thermionic Cooling for Domestic Refrigeration | RA Lewis, C Zhang |
| M Farhoudi | Synthesis and characterization of transition material oxide | XL Wang, SX Dou, M. James |
| D Fisher | Dissipation Effect in Resonant Tunnelling through Double Barrier Structures | C Zhang |
| F. Gao | Preparation and Characterisation of Colossal Magnetoresistance Materials | SX Dou, RA Lewis |
| ZP Guo | Improvement of energy density and cycle life of nickel metal hydride batteries | HK Liu, SX Dou |
| ZG Huang | Analates for hydrogen storage | HK Liu, ZP Guo, SX Dou |
| S.Keshavarzi | Investigation of Flux Dynamics of HTS and $MgB_2$ | MJ Qin, J. Horvat, SX Dou |
| P Lavers | Electronic structure of perovskites | QM Qin, SX Dou |
| A Li | YBCO thick and thin films | M Ionescu, HK Liu |
| G Li | Numerical Analysis on Electromagnetic Behaviour of High Tc Superconductors in Magnetic Field | HK Liu, MJ Qin |
| M Lindsay | Anode and Cathode Materials for Lithium Ion Batteries | HK Liu, GX Wang |
| B Lough | Thermionic Cooling with Semiconductor Multilayers | RA Lewis, C Zhang |
| J McKinnon | Y-123 Ceramic Film on Single-Crystal Substrates by Laser Ablation | M Ionescu, J Horvat |
| LQ Mai | Multilayers for solar cells and Li battery | HK Liu, SX Dou |
| D Marinaro | Flux Pinning Mechanism in Thermal Neutron Irradiated -doped HTS | SX Dou, J Horvat |

| PhD | Thesis Title | Supervisors |
|---|---|---|
| D Milliken | Enhancement of Flux Pinning through Uranium Doping and Neutron Irradiation in Bi-2223 Tapes | SX Dou, YC Guo |
| S. Needham | Large scale Li-ion battery | GX Wang, H.K. Liu |
| SH Ng | Nano-materials for electrode in Li-ion battery | HK Liu, JZ Wang, SX Dou |
| M O'Dwyer | Thermionic cooling and power generation | C Zhang, RA Lewis |
| G. Peleckis | Spintronic materials | XL Wang, SX Dou |
| SH Pilehrood | Electronic Properties of Semiconductor Nanostructures under Intense Terahertz Radiation | C Zhang |
| M Roussel | MOI of Superconductors | SX Dou, A Pan, T Johansen |
| O.Scherbakova | Two-gap superconductors | SX Dou, MJ Qin |
| M Smith | T Ray spectroscopy | RA Lewis, C. Zhang |
| S Soltanian | Characterisation of CMR Materials & $MgB_2$ | SX Dou, XL Wang |
| K Uprety | Vortex properties of Bi-HTS | SX Dou, J Horvat |
| C Wang | Investigation of Positive Electrodes for Ni-MH Batteries | HK Liu, SX Dou |
| J. Wang | Bipolar electrode materials and design for electric vehicles | HK Liu, SX Dou |
| Y Zhao | Fabrication and Characterization of $MgB_2$ Films | SX Dou, M Ionescu |
| SH Zhou | Density Evaluation During Processing of Bi-2223/Ag Tape | HK Liu, A Pan |
| J Yao | Thin film microbattery | K. Konstantinov H.K. Liu |
| WK Yeoh | Control of Nanostructure for Enhancing Superconductor Performance through Chemical Doping | SX Dou, J Horvat |
| L Yuan | Nano-materials for use in Li-ion Batteries | HK Liu K Konstantinov GX Wang |

| Masters | Thesis Title | Supervisors |
|---|---|---|
| T. Ha | Electronic properties of modulated two dimensional semiconductors | C Zhang |
| Z.J. Lao | Ceramic Materials for Laser Application | K Konstantinov |
| PS Lavers | The Mobility of Large Anions in Crystals with the Fluorite Structure | AD Martin |
| S Lee | Multilayer thermionic cooling in semiconductor heterostructures | RA Lewis, C Zhang |
| H Ta | Electronic Properties of Modulated Two Dimensional Semiconductors | C Zhang |
| B. Winton | Bi-2212 for magnetic sensor | SX Dou, M Ionescu |
| J Yao | Nanocarbon tube for anode materials of Li-ion batteries | HK Liu, JH Ahn |
| Q Yao | $MgB_2$ Thick Films | XL Wang, SX Dou |
| Z Zhang | Characterisation of Sheathed Bi-2223 HTS Tapes | HK Liu, M. Apperley |
| ZW Zhao | Spray Pyrolysis Technique for Processing Cathode Materials | K Konstantinov, HK Liu |

## Completions

| PhD<br>Name & Thesis Title | Awarded | Position | When Appointed |
|---|---|---|---|
| M Apperley<br>The Fabrication of High Tc Superconductor Wire | 1992 | Chief Technologist<br>Australian Superconductors | 1993 |
| R Baker<br>Zeeman and Piezospectroscopy of Antimony and Aluminum in Germanium | 2001 | Professional Officer<br>University of Wollongong | 2003 |
| A Bourdillion<br>Microstructure, Phase Characterisation and Texture Processing of HTS | 1992 | Senior Engineer<br>Hewlett Packard, Singapore<br>Hewlett Packard, USA | 1993<br><br>2000 |
| Jobe Probakar Chelliah<br>Optical spectroscopy of semiconductors | 2000 | | |
| J Chen<br>High Energy Storage Material for Rechargeable Nickel-Metal Hydride Batteries | 1999 | NEDO Fellow<br>Osaka National Research Institute<br>Professor<br>Nankai University, China | 1999<br><br><br>2002 |
| N Cui<br>Magnesium Based Hydrogen Storage Alloy Anode Materials for Ni-MH Secondary Batteries | 1998 | Research Fellow<br>Alberta University, Canada<br>Electrochemist<br>Energizer Co, USA | 1997<br><br>2000 |

| PhD<br>Name & Thesis Title | Awarded | Position | When<br>Appointed |
|---|---|---|---|
| F Darmann<br>Characterisation of melt-texture Y-123 materials | | Research Fellow<br>ANSTO | 2003 |
| XK Fu<br>Superconducting current leads using Bi-HTS | 2002 | Research Fellow<br>Texas A&M University, USA | 2002 |
| YC Guo<br>Investigation of Silver-clad $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10-x}$ Superconducting Tapes | 1994 | STA Fellow<br>Nat. Res. Inst. Of Metals, Japan<br>ARC Postdoctoral Fellow<br>ISEM, University of Wollongong | 1997<br><br>1998 |
| ZP Guo<br>Improvement of energy density and cycle life of nickel metal hydride batteries | 2003 | ARC Postdoctoral Fellow<br>ISEM, University of Wollongong | 2003 |
| RJ Heron<br>Far-infrared Studies of Semiconductors in Large Magnetic Fields | 1998 | Postdoctoral Fellow<br>SUNY, Buffalo, USA | 1997 |
| QY Hu<br>Fabrication and Enhancement of Critical Currents of Silver Sheathed $Bi,Pb_2Sr_2Ca_3Cu_3O_{10}$ Tapes | 1996 | Research Fellow<br>Florida State University USA<br>Research Scientist<br>Argonne National Lab., USA<br>Senior Engineer, Lucent, USA | 1997<br><br>1999<br><br>2001 |
| M Ionescu<br>Growth and Characterisation of Bi-2212 Crystals and Improvement of Bi-2212/Ag Superconducting Tapes | 1998 | Assistant Director<br>ISEM, University of Wollongong | 1994 |
| JX Jin<br>$(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10+x}$/Ag High $T_c$ superconductors and their Applications in an Electrical Fault Current Limiter and an Electronic High Voltage Generator | 1998 | Research Fellow<br>ISEM, University of Wollongong<br>ARC, PDF<br>ISEM, University of Wollongong | 1997<br><br>2000 |
| M Lerch<br>Optical & Electrical Studies of Resonant Tunnelling Heterostructure | 1998 | Research Fellow<br>Medical Physics | 1999 |
| BL Luan<br>Investigations on $Ti_2Ni$ Hydrogen Storage Alloy Electrode for Rechargeable Nickel-Metal Hydride Batteries | 1997 | NRC Fellow<br>National Res. Council of Canada<br>Group Leader<br>Shape Transfer Process<br>Integrated Manufacturing<br>Technologies Institute, NRC, Canada | 1997<br><br>1999 |
| J McKinnon<br>Y-123 Ceramic Film on signle-crystal substrates by laser ablation | 2003 | Teacher<br>New South Wales Education Department | 2003 |
| D Marinaro<br>Flux pinning mechanism in thermal neutron irradiate-doped HTS | 2003 | Scientist<br>DSTO | 2003 |
| D Shi<br>Investigation of Buffer Layer for Y-123 Coated Conductor Using Laser Ablation | 2002 | Research Fellow<br>Korean Electrical Technology Institute, Korea | 2002 |
| T Silver<br>Near Bandedge Optical Properties Of MBE GaAs And Related Layered Structures | 1999 | Research Fellow<br>ISEM, University of Wollongong | 2000 |

| PhD<br>Name & Thesis Title | Awarded | Position | When<br>Appointed |
|---|---|---|---|
| K Song<br>Processing And Characterisation Of Superconducting Ag/BiPbSrCaO Composite | 1992 | Senior Engineer<br>South Korean Co | 1993 |
| S Stewart<br>Thermodynamic And Dielectric Properties In Modulated Two-Dimensional Electronic Systems | 1998 | ARC Postdoc. Fellow<br>Teacher | 1998<br>1999 |
| L Sun<br>Amorphous And Nanocrystalline Hydrogen Storage Alloy Materials For Nickel-Metal Hydride Batteries | 2000 | Research Associate<br>Hydro-Quebec Research Institute, Canada<br>Research Fellow<br>University Sherbrooke, Canada | 2000<br><br>2002 |
| G Takacs<br>Spectroscopy Of The Effect Of Strains And Magnetic Field On Shallow Acceptor Levels In Germanium | 1999 | Lab Manager<br>2nd Year Physics Lab | 1999 |
| K. Uprety<br>Vortex Properties of Bi-HTS | 2002 | Research Fellow<br>Argonne National Lab., USA | 2002 |
| N Vo<br>Design And Characterisation Of HTS Coils | 1997 | Research Fellow<br>Los Alamos Nat. Lab, USA<br>Research Staff<br>Intermagnetics General Co., USA | 1999<br><br>1998 |
| GX Wang<br>Investigation on electrode materials for lithium-ion batteries | 2001 | ARC Postdoc. Fellow<br>ISEM, University of Wollongong | 2001 |
| J Wang<br>Bipolar electrode materials and design for electric vehicles | 2003 | ARC Postdoctoral Fellow<br>ISEM, University of Wollongong | 2003 |
| WG Wang<br>Fabrication And Improvement Of Silver Sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ Tapes By Powder-In-Tube Technique | 1998 | R&D Manager<br>Nordic Superconductor Tech.<br>Denmark | 1997 |
| XL Wang<br>Spiral Growth, Flux Pinning And Peak Effect In Doped And Pure Bi-2212 HTS Single Crystal | 2000 | Research Fellow<br>ISEM, University of Wollongong<br>ARC Postdoctoral Fellow<br>ISEM, University of Wollongong | 1999<br><br>2002 |
| A Warner<br>A Spectroscopic Study of Acceptors in Germanium | 1997 | Consultant<br>Computer Industry | 1999 |
| JA Xia<br>Characterisation of Melt-Texture of YBCO HTS | 1994 | Research Fellow<br>Solar Cell Ltd | 1995 |
| JM Xu<br>Phase Formation and Transformation in the R-Fe-T System (R=Nd, Gd, Tb, Dy, Er, Ho, T and Lu, T=Si, Ti & Zr | 1997 | Research Fellow<br>St. George Bank, Australia | 1998 |
| J Yau<br>Ag/Bi-2223 Tape Processing and Mechanical Properties | 1994 | Assistant Professor<br>City Polytechnical University | 2000 |
| M Yavus<br>Powder Processing of Bi-Pb-Sr-Ca-Cu-O Superconducting Materials | 1997 | Ass. Professor<br>Texas A&M University, Texas USA<br>Ass. Research Professor<br>Tohoku University,Sendai, Japan<br>Ass. Professor<br>University of Waterloo, Canada | 2000<br><br>1997<br><br>2004 |
| B Zeimetz<br>High Temperature Superconducting Tapes & Current Leads | 1998 | Research Fellow<br>Cambridge Univ., U.K. | 1999 |

| PhD<br>Name & Thesis Title | Awarded | Position | When Appointed |
|---|---|---|---|
| S Zhong<br>Investigation on Lead-Calcium-Tin-Aluminium Grid Alloys for Valve-Regulated Lead-Acid batteries | 1998 | ARC Postdoc. Fellow<br>ISEM, University of Wollongong<br>CEO, Leadcel Dynamic Energy Ltd, P.R. China | 1997<br><br>2002 |
| R Zeng<br>Processing and characterisation of Bi-2223/Ag superconducting tapes | 2000 | Research Fellow<br>ISEM, University of Wollongong | 2000 |

| Masters<br>Name & Thesis Title | Awarded | Position | When Appointed |
|---|---|---|---|
| F Chen<br>The Influence of Selenium on Lead-Calcium-Tin-Aluminium | 1998 | PhD candidate<br>University of Sydney, Australia | 1999 |
| M Farhoudi<br>AC Loss of Ag/Bi-2223 Tape in AC Field | 2002 | PhD candidate<br>ISEM, University of Wollongong | 2003 |
| JX Jin<br>$(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10+x}$/Ag High $T_c$ Superconductors and their Applications in an Electrical Fault Current Limiter and an Electronic High Voltage Generator | 1994 | Research Fellow<br>ISEM, University of Wollongong<br>ARC, PDF<br>ISEM, University of Wollongong | 1997<br><br>2000 |
| A Li<br>Novel substrates for Bi-Sr-Ca-Cu-O superconducting | 2002 | PhD Candidate<br>ISEM, University of Wollongong | 2002 |
| M Ling<br>Mechanism of Outgrowth in Multifilament Bi-2223 tape | 2001 | Taiwan | |
| E. Sotirova<br>Investigation of Colossal Magnetoresistance Materials | 2001 | Learning Centre Employee<br>Communications Assistant<br>Star CD Pty Ltd | 2002 |
| K Uprety<br>Vortex Properties of Bi-HTS | 1999 | PhD Candidate<br>ISEM, University of Wollongong<br>Research Fellow<br>Argonne National Lab., USA | 2000<br><br>2003 |
| JZ Wang<br>Investigations on Anode Materials For Rechargeable Lithium-Ion Batteries | 1999 | PhD Candidate<br>ISEM, University of Wollongong<br>Research Fellow<br>IPRI, University of Wollongong | 2000<br><br>2003 |
| G Yang<br>Effect of Element Substitution on Superconductivity | 1997 | Research Fellow<br>University of Melbourne | 2000 |
| N Zahir<br>A New Method for Production and Study of Electrical Properties of Carbon Foam | 1996 | PhD Candidate<br>Queensland University | 1997 |
| Z. Zhang | 2003 | Senior Staff<br>China-URC Ltd, Shanghai. PR China | 2003 |
| M. Farhoudi | 2003 | PHD Candidate<br>ISEM, University of Wollongong | 2003 |

# 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 Organisation | Dr. S. Kennedy, Dr. M. James, Dr M. Reinhard |
| University of Sydney | Dr. S. Ringer, Dr. R. Keast |
| Curtin University of Technology | A/Prof. J Low |
| Macquarie University | A/Prof. E. Goldys |
| University of Technology, Sydney | Prof. G. Smith |
| Monash University | Dr. Y.B. Cheng, Krishnamurthy |
| University of Melbourne | Prof. D. Jamieson |
| University of New South Wales | Dr. R. Ramer, Prof. M.S. Kazakos, A/Prof. P. Munroe |
| University of Western Sydney | Prof. M.M. Wilson |
| University of Queensland | Prof. G.Q.M. Lu |

**International**

| | |
|---|---|
| Atomic Institute of Austrian Universities, Vienna, Austria | Prof. H.W. Weber |
| Brookhaven National Lab | Dr. X.Q. Yang, Dr. Y.M. Zhu |
| Dalhousie University, Canada | Prof. J. Dahn |
| Houston University, USA | Prof. R. Weinstein |
| Institute for Metal Physics, Kiev, Ukraine | Prof. V. Pan |
| Los Alamos National Lab | Drs A. Serquis and X.Z. Liao |
| Ludwig Boltzmann Institut für Festkörperphysik, University of Vienna, Austria. | Dr. W. Lang |
| Max-Planck Institute for Metals Research, Germany | Dr. E.H. Brandt |
| Max-Planck Institute for Solid State Physics, Germany | Prof. U. Habermeier |
| Nankai University, PRC | Prof. J. Chen, Prof. Y.H. Tang |
| Nanjing University | Prof. S.Y. Ding, Prof. W.M. Chen |
| Nanyang Technological University | Prof. S. Li |
| National Andong University | Prof. J.H. Ahn |
| Northeatern University, Shenyang, PRC | Prof. X.D. Sun |
| Ohio State University, Columbus, OH, USA | Dr. E.W. Collings, Dr. M. Sumption |
| Osaka National Reseach Institute, Japan | Dr. T. Sakai |
| University of Auckland | Prof. W. Gao |
| University of Cincinnati | Prof. D. Shi |
| University of Wisconsin | Prof. D. Larbalestier, Dr. A. Polyanskii |
| University of Zagreb, Zagreb, Croatia | Prof. E. Babic, I. Kusevic |
| Yamagata University, Japan | Dr. S. Kambe, Prof. Ohshima |
| Kyushu Institute of Technology | Prof. T. Masushita |
| Institute of Physics, Chinese Academy | Prof H.H. Wen |
| University of Geneva | Prof. R. Flukiger |
| Korean Advanced Institute of Science & Technology | Prof. J.Y. Lee |
| Imperial College | Dr. Cohen, |
| Philips Research Laboratories and Technical University Eindhoven, The Netherlands | Prof. Dr PHL Notton |

# Progress Reports for Projects funded by the Australian Research Council

## 1. Progress Reports on ARC Large/Discovery Projects

***Enhancement of critical current density and flux pinning in BiPbSrCaCuO systems by fission tracks***

| | | | |
|---|---|---|---|
| **Funded:** | 2001 | 2002 | 2003 |
| **Project ID:** | A00104022 | | |
| **Chief Investigator:** | S.X. Dou | | |
| **Research Fellow:** | T. Silver | | |
| **Postgrad. students:** | D. Marinaro, D. Milliken | | |

The objective of this project is to enhance flux pinning in bismuth based high temperature superconductors (BSCCO HTS) by using a combination of stable uranium compound doping and thermal neutron irradiation to produce fission fragments to act as pinning centres. The enhanced flux pinning is expected to lead to improved $J_c$ in magnetic fields and minimised anisotropy of HTS compounds.

**Increased pinning in melt-textured Bi2212 by Uranium Oxide addition**: Two types of pinning mechanisms were identified in Bi2212 melt-textured with Uranium Oxide addition. The first mechanism results from the addition of U-O and partial decomposition of Bi2212 phase in the proximity of U-O particles, where some Ca, Sr and Cu atoms are extracted from the Bi2212 structure, resulting in a Sr-, Ca- and Cu-depleted Bi2212 phase. The released Ca and Sr oxides, together with U oxide, form a new compound, $UsrCaO_5$, whilst CuO remains as a separate phase. The second mechanism results from the splayed fission tracks following the neutron irradiation and fission of $^{235}U$ atoms. A quantitative assessment of these two pinning effects was carried out by AC susceptibility and DC magnetization at a temperature of 5K. It was found that in the presence of U-O, Bi2212 shows a strong increase in the flux pinning as compared to a control sample containing no U-O.

**Application of U/n process to $MgB_2$:** The U/n method is a well-established means of improving flux pinning and critical current performance in cuprate superconductors. The method involves doping of the superconductor with $^{235}U$ followed by irradiation with thermal neutrons to promote fission. The resultant columnar damage tracks produced by the energetic fission products pin flux vortices and improve critical current performance in magnetic fields. No such improvement was observed when the U/n method was applied to $MgB_2$ superconductor. No fission tracks were observed in TEM, even for samples irradiated at the highest fluence. Gamma-ray spectroscopy indicated that fission had occurred in the expected way. The likely resistance of $MgB_2$ to the formation of fission tracks is highly relevant to attempts to improve flux pinning and superconducting performance in this material through the introduction of columnar defects.

**Enhanced flux pinning by isotropic fission tracks in U-dped Bi-2223:** By DC magnetic measurements, we have confirmed the significant enhancement of vortex pinning by the fission-induced randomly oriented tracks in the Ag-Bi-2223 tapes. The flux motion is found to be quite different for the samples with and without fission tracks. A two dimentional vortex glass model is suggested to explain the non-existance of "plateau" or "peak in the temperature dependence of creep rate for the sample with fission tracks. This scenario is attributed to the combination of the crossing-track induced zigzag excitations and high anisotropy of Bi-2223, and is proved to be reasonable by a good scaling considering a finite pinning correlation length.


- D.G. Marinaro, J. Horvat, S.X. Dou, R. Weinstein and A. Gandini "Effects of fission-fragment damage on vortex dimensionality in silver-sheathed $Bi_2Sr_2Ca_2Cu_3O_x$ tapes" *Phys. Rev. B* **68**, 0645181-1, 0645181-9 (2003)
- S. Ohshima, K. Ujiie, T. Kawai, K. Moriai, H. Yamada, D.G. Marinaro and S.X. Dou "Observation of vortex distribution in samples of Bi-2223 Ag-sheathed tapes with and without uranium doping by means of the high-resolution bitter method" *IEEE Trans. On Appl. Supercond.* **13, 2** 2953-2955 (2003)

A. Gandini, R. Weinstein, D. Parks, R.P. Sawh and S.X. Dou "A non-destructive, non-contact, quality test of critical current for Ag-BISCCO tape" *IEEE Trans. On Appl. Supercond.* **13, 2** 3332-3334 (2003)

A. Gandini, R. Weinstein, D. Parks, R.P. Sawh and S.X. Dou "On the limiting mechanism of irradiation enhancement of $I_c$" *IEEE Trans. On Appl. Supercond.* **13, 2** 2934-2936 (2003)

***Growth, characterization, and flux pinning behaviour of doped $TlSr_2Ca_2Cu_3O_y$ and $TlSr_2CaCu_2O_y$ high temperature superconducting single crystals***

| | | | |
|---|---|---|---|
| **Funded:** | 2001 | 2002 | 2003 |
| **Project ID:** | A00103044 | | |
| **Chief Investigator:** | H.K. Liu | | |
| **Assoc. Investigator:** | M. Ionescu & X.L. Wang | | |
| **Research Fellow:** | Z.X. Cheng | | |

**(Tl,Pb)(Sr,Ba)2Ca2Cu3O*y* single crystals grown by self-flux follow a layer-by-layer growth mechanism.** Periodic modulation structure 200 nm in width and about 0.7-0.8 nm in height has been observed using AFM. Most of the crystals investigated by optical microscopy and SEM have at least one flat plane. The crystals show a rectangular shape, which is in agreement with the tetragonal crystal structure of the 1223 phase. Some dark brown particles were found on the surface of some crystals. These contaminations were determined to be Tl-Cu oxide, which obviously comes from the flux, indicating the crystals were grown surrounded by fluxes of Tl-Cu-O. A common feature of the crystal surface morphologies is their layer by layer growth pattern.

The nature surface morphology of the as-grown single crystals provides evidence of crystal growth mechanism. Typical line growth steps on the a-b plan imply a layer-by-layer mechanism. The ratio of step width to step thickness depends on the growth competition between a-b plane and c-axis. It is obvious that the Tl-1223 single crystal grown in CuO-TlO self-flux system abide a two-dimensional nucleation mechanism. Periodic modulation structure on the smooth new cleaved a-b surface of the modified Tl-1223 single crystal was observed. Comparing the parameters of the unit cell of the Tl-1223 single crystal, the period is about 50 times longer of a-axis and a half height of the c-axis. Such modulation structure was thought to be due to the composition modulation. Since there are two elements, Pb and Sr for the substitution of Tl and ba respectively in the Tl-based single crystals, we believe that the modulation structure may be attributable to regular composition variation within the crystal matrix.

**Heat treatment effect on superconductivity of Tl-based single crystals**: Before annealing, the $T_c^{onset}$ of the sample was 103 K and became 106 K after annealing for 3 h at 500$^o$C in pure argon, while the sample heat treated in pure oxygen or pure argon for a longer period showed a little lower $T_c^{onset}$. The reason is that the as grown single crystal is oxygen over doped, the heat treatment in argon for 3 h may adjust the oxygen content to suitable amount, while the heat treatment in argon for 6 h may decrease the oxygen content too much and the heat treatment in $O_2$ for 25 h make the sample with oxygen over doped. After all the heat treatment, the maximum diamagnetic moment decreased due to the reduction of superconductor volume as the decomposition occurred at the sample surface. A longer heat treatment (25 h) resulted the sample decomposed seriously. The lost of Tl in the crystal also contributed to the change of $T_c$.

**All samples showed an apparent peak effect:** The magnetic hysteresis loops at temperatures of 20 K, 30 K and 40 K were measured and the $J_c$ were calculated by the Bean's model to evaluate the effect of heat treatment. Very large magnetic current was obtained compared with other high temperature superconducting crystals, which may be due to the periodic modulation structure enhanced flux pinning in the crystal. Peak effect indicates an anomalous increase in the measured current density with increasing applied magnetic field. The different heat treatment conditions have little effect on the peak shape and position but do affect the magnitude of the peaks. The sample after heat treated in pure argon for 3 h showed the highest magnetic $J_c$ compared with original and other samples treated in oxygen at the same temperature for 3 h, which is due to the defects or variation of oxygen content. The optimal heat treatment can adjust the defects caused by over doped oxygen and disperson distance to be more favorable for the flux pinning. Another reason for the enhancement of the magnetic critical current is that the heat treatment changed the content of Tl and Pb in the crystal. For the crystal studied, the Tl content will loss more than Pb after heat treatment because of the easier volatile properties of Tl.

5 Papers from this project were published in 2003.

*Investigation of nano-materials for use in lithium rechargeable batteries*

| | | | |
|---|---|---|---|
| **Funded:** | 2002 | 2003 | 2004 |
| **Project ID:** | LP0219309 | | |
| **Chief Investigator:** | H.K. Liu | | |
| **Assoc. Investigator:** | S. Zhong, J.H. Ahn | | |
| **Industry Partners:** | Sons of Gwalia, OM Group, Lexel Battery Ltd | | |

**Tin, Tin-oxide and NiSn-based nanocomposites with $Al_2O_3$ dispersion as new anode materials** were prepared by high energy ball milling. Electrochemical tests demonstrated that the initial charge-discharge capacities are very high for these materials (the first charge capacity of the Sn-$Al_2O_3$ electrode was 980 mAh/g, while that of $SnO_2$-$Al_2O_3$ electrode was 600 mAh/g)). However, the nanosize oxide dispersion did not improve cycle life, the capacity faded rapidly after the first cycle due to irreversible reactions. This thought to be caused by the separation of the active materials from the inert oxide particles. The initial cycling efficiency was markedly improved by subsequent annealing of the ball-milled new anode materials.

**Nanosize cobalt oxides ($Co_3O_4$)** were synthesized by chemical decomposition of cobalt octacarbonyl ($Co_2(CO)_8$) in toluene at the temperature of 130$^o$C. The crystallinity and microstructure were characterized using X-ray diffraction and scanning electron microscopy. The as-prepared nanosized $Co_3O_4$ powders were used as the anode material in lithium cells, they demonstrated high lithium storage capacity of about 360 mAh/g over 30 cycles (good cyclability). The nanosize $Co_3O_4$ particles provide high reactivity to the lithium insertion, which possibly contributes to the large lithium storage capacity. On the other hand, a stable passivation film may form on the surface of the nanosize $Co_3O_4$ electrode that may enhance the stability of the electrode on cycling. Thus nanosize cobalt oxides ($Co_3O_4$) is promising for their use as anode materials in commercial lithium-ion batteries.

**Nanoparticle-dispersed polymer electrolytes** were prepared by stirring or high-energy ball milling of polyethylene oxide (PEO), llithium salt ($LiCF_3SO_3$, $LiClO_4$ and $LiPF_6$), and nanometer-size ceramic powder ($TlO_2$, $SiO_2$ and $Al_2O_3$). The smaller the size of of ceramic particles, the better they influence the crystallization kinetics of the PEO polymer chains. High-energy ball milling lowers the glass transition temperature of the composite polymers, and thus increases the ionic conductivity greater than the order of the magnitude compared with the un-milled samples. The highest ionic conductivity was obtained when using $LiPF_6$ as added lithium salt and $Al_2O_3$ as dispersed particle. Cyclic voltametric measurements showed that the PEO-system is electrochemically stable in the range of 2-5 V.

C1, Y. Chen, G.X. Wang, K. Konstantinov, J.-H. Ahn, H.K. Liu, S.X. Dou, “Studies of the electrochemical properties of nanosize $Co_3O_4$ oxide as anode materials for lithium-ion batteries”, J. Metastable and nanocrystalline materials, **15-16**, 625-628 (2003)

C1, J.-H. Ahn, G.X. Wang, J. Yao, H.K. Liu, S.X. Dou, “Tin-based composite materials as anode materials for Li-ion batteries”, J. Power Sources, **119-121**, 45-49 (2003)

C1, M.J. Linday, G.X. Wang, H.K. Liu, “Al-based anode materials for Li-ion batteries”, J. Power Sources, **119-121**, 84-87 (2003)

*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 | | | | |
| **Assoc. Investigator:** | H. Weber, E.W. Collings, E. Habermier | | | | |

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 focussing on the complex interplay between physics, fabrication and materials issues. The knowledge gained will make possible improvements in the development of HTS conductors.

**Enhancement of $H_{c2}$ by impurity scattering:** The effect of nanoscale-SiC doping of $MgB_2$ was investigated in comparison with undoped, clean limit and Mg exposed samples using transport and magnetic measurements. The results show that there are two distinguishable but closely related mechanisms that control the performance of $J_c(H)$ in these samples: increase of $H_{c2}$ and improvement of flux pinning. SiC-doping introduced many nano-scale precipitates and disorder at B and Mg sites, provoking an increase of $\rho(40K)$ from 1 $\mu\Omega$-cm (RRR = 15) for the clean limit sample to 300 $\mu\Omega$-cm (RRR = 1.75) for the SiC-doped sample, leading to significant enhancement of both $H_{c2}$ and H* with only a minor effect on $T_c$. EELS and TEM analysis revealed impurity phases at a scale below 10nm and an extensive domain structure of 2-4nm domains in the doped sample, which serve as strong pinning centers. $J_c$ for the nano-SiC doped sample increased substantially at all fields and temperatures.

**$J_c$ optimisation of HTS conductors by improving grain connectivity:** A set of Ag-sheathed Bi-2223 ($Bi_{1.72}Pb_{0.34}Sr_{1.85}Ca_{1.99}Cu_3O_x$) tapes was produced using the powder in tube technique and two heat treatments with an intermediate mechanical deformation. The tapes were comparatively studied by "local" (Magneto-optical imaging) and "global" (X-ray diffraction, magnetization and transport measurements) techniques. It is shown that the "local" results correlate with global outcomes. The different measurements indicate better superconducting properties (higher $J_C$, better shielding properties) for the slow cooled sample and for the sample annealed at 750˚C during the second step of the second sintering stage.

**Improvement of $J_c$ by ferromagnetic sheath:** We found that a ferromagnetic sheath around a superconductor can improve the field dependence of $J_c$ much more strongly than by merely shielding the external field. Our new results showed that there is a peak in the field dependence of $J_c$, caused by the interaction between the superconductor and ferromagnetic sheath. This interaction seems to be dependent on the magnetization state of the ferromagnet: when the current is applied to the sample after the change of the external field, different values of $J_c$ are obtained before and after re-magnetizing the sheath by the self-field of the current. Changing the direction of the current in each subsequent measurement generally results in an increase of $J_c$, which may be beneficial for the AC current applications. 4 book chapters and 10 papers have been published.


S.X. Dou, A.V. Pan, S. Zhou, M. Ionescu, X.L. Wang, J. Horvat, H.K. Liu and P.R. Munroe "Superconductivity, critical current density, and flux pinning in $MgB_{2-x}(SiC)_{x/2}$ superconductor after SiC nanoparticle doping" *J. Appl. Phys.* **94, 3,** 1850-1856 (2003)

S. Li, T. White, K. Laursen, T.T. Tan and C.Q. Sun, Z.L. Dong, Y. Li, S.H. Sho, J. Horvat and S.X. Dou "Intense vortex pinning enhanced by semicrystalline defect traps in self-aligne d nanostructured $MgB_2$" *App. Phys. Lett.* **83, 2,** 314-316 (2003)

X. Leng, S.Y. Ding, Y. Liu, Z.H. Wang, H.K. Liu and **S.X. Dou,** "Dip effect of ac susceptibility due to surface barrier with flux creep", *Phys. Rev B68* 214511-1-5 (2003)

S. Soltanian, M.J. Qin, S. Keshavarzi, X.L. Wang and S.X. Dou "Effect of sample size on the magnetic critical current density in nano-SiC doped $MgB_2$ superconductors" *Phys. Rev. B* ***68,*** *134509-1 134509-4 (2003)*

***Enhancement and elucidation of flux pinning in doped Bi-Sr-Ca-Cu-O high temperature superconducting single crystals***

| | | | |
|---|---|---|---|
| **Funded:** | 2002 | 2003 | 2004 |
| **Amount Funded:** | $61,184 | $62,967 | $62,967 |
| **Total Funding:** | **$187,118** | | |
| **Project ID:** | DP0211328 | | |
| **Chief Investigator:** | X.L. Wang | | |

The project proceeded as planned. Various crystals scheduled in the original proposal have been successfully grown and some of them are well characterized. More international collaborations have been established. The followings are results obtained in the year 2003 period:

1. $Bi_{2-x}Pb_xSr_2Ca_{1-y}Gd_yCu_2O_{8+\delta}$ (x=0, 0.34 and y=0.12, 0.34) single crystals were grown by the self-flux method and characterized using SEM, AFM and magnetic measurements. The doped crystals have a cleavage thickness of from only half a unit cell up to two unit cells. $T_c$ only dropped 20 K as y increased from 0.12 to 0.34 for as-grown crystals. However, the $T_c$ increased to almost the same value of about 80 K after annealing in air regardless of the Gd doping levels in both Gd and heavily Pb co-doped crystals. Both Gd and heavy Pb co-doping produced enhanced flux pinning compared to sole Gd doping. A pronounced secondary peak effect was present in x=0.34 and y= 0.34 samples, but absent in samples with x=0.34 and y=0.12. Phase segregations containing Gd clusters were proposed to be responsible for the presence of the peak effect in the samples with higher Gd and Pb doping levels.

2. Vortex dynamics of Pb+Gd co-doped single crystals were also studied by magnetic hysteresis and relaxation measurements. Results showed that co-doping produced an enhancement of flux pinning and a pronounced peak effect at low fields with a slow relaxation rate. However, the pinning is weaker and the relaxation rate is faster in high fields compared to sole Gd doped samples. The evolution of a vortex system changing from 3D to 2D in different fields was studied.

3. In cooperation with Prof. T.H. Johanson at the University of Oslo, Norway, magnetic flux behaviours in crystals produced by this project have been directly visualized using an high resolution magneto-optical imaging technique. The crystals showed some interesting flux penetration patterns strongly deviating from classical Bean-model flux penetration. There are present in the images distinct lines where flux accumulates in an increasing applied field. The same set of defects also becomes clearly visible when the temperature is increased in the set of remanent states.

4. On the emergence of the newly discovered superconductor magnesium diboride, the CI also carried out studies on crystal growth and characterisation on the new superconductor under the support of the APD fellowship. Single crystals of magnesium diboride with maximum dimensions of $200\times200\times60\ \mu m^3$ have been successfully grown from copper flux in iron capsules. The $MgB_2$ single crystals were well characterised by polarized light, magneto-optical microscopy and magnetic measurements. This work is in press at the Journal of Crystal Growth.

***Fabrication, Charge and Spin Ordering, Magnetoresistance, and polaron effects in nano-size and single crystals of novel transition metal perovskite oxide***

| | | | |
|---|---|---|---|
| **Funded:** | 2003 | 2004 | 2005 |
| **Amount Funded:** | $90,000 | $77,000 | $78,000 |
| **Total Funding:** | **$245,000** | | |
| **Project ID:** | DP0345012 | | |
| **Chief Investigator:** | X.L. Wang, M. Ionescu, Z.X. Cheng | | |
| **Partner Investigator:** | Dr.M James, Prof. R.S. Liu, Prof. W. Lang | | |
| **Postgraduate students:** | M. Farhoudi | | |

ARC Discovery Grant: "The fabrication, charge and spin ordering, magnetoresistance, and polaron effects in

The project has proceeded as planned. Various new materials scheduled in the original proposal have been successfully made and some of them are well characterized. The followings are results obtained in the year 2003 period:

1. Doping effects on the physical properties have been studied for $RE_{1-x}Sr_xCoO_3$ (RE=Y and Gd, x=0, ½, 1/3) compounds. The spin state of Co takes a low spin in $SrCoO_3$ exhibiting a magnetoresistance behavior and a possible spin glass state. $Y_{½}Sr_{1/2}CoO_3$ is antiferromagnetic. $Gd_{1-x}Sr_xCoO_3$ (x=1/3 and ½) were found to be ferromagnetic and to have a large magnetoresistance for x=1/2 samples. Spin glass states are also present in the $Sr_{1-x}Gd_xCoO_3$ system.

2. $Y_{1/3}Sr_{2/3}CoO_{3-x}$ has been studied magnetically and the structures were characterized using neutron diffraction. Rietveld refinements suggest that Co moments are arranged antiferromagnetically below 320 K in agreement with magnetic measurements. A paper has been submitted.

3. Polycrystalline $La_{0.67-x}Bi_xSr_{0.33}MnO_3$ (x=0.1, 0.2, 0.3 and 1) compounds were prepared and their structural, magnetic and transport properties were well studied. The Bi substitution leads to a decrease in the lattice parameter, but the structures remained cubic for $x \leq 0.3$ and changed to tetragonal for x=1. Ferromagnetic transitions were also reduced from 370K down to 330K with increases of x up to 0.3. Resistivities and metal-insulator transitions were also observed to increase and decrease with x, respectively. The work will be presented at an international workshop. A full paper was submitted.

4. Thin films of $La_{1-x}A_xMnO_3$ (A=Sr or Ca) were fabricated using sol-gel spin coating and laser ablation methods. Films were well characterized using AFM, SEM, XRD, and transport, magnetic, and optical measurements. The thermal resistivity and FIR reflectance of the thin films were obtained. The far-infrared reflection spectrum of a thin film is qualitatively different from that of bulk. The reflectance of the thin film exhibits a new mode which is not present in the bulk sample. Papers are under preparation and submitted.

5. Structures and magnetic properties of $Gd_2Co_{1-x}Mn_xO_6$ (x=0-1) have been well studied. It was found that the ferromagnetic transition $T_c$ decreases as x decreases. Spin-glass is present in all the samples.

6. The processing, microstructures and properties of $La_{0.7}Sr_{0.3}M_{1-x}Zn_xO_3$ (x=0, 0.1, 0.2, and 0.3) have been investigated. The resistivity increases with an increasing zinc doping level. The magnetization value is greatest for x=0.1 and drastically decreases with x>0.1. Meanwhile, the compound changes from ferromagnetic to paramagnetic. The ferromagnetic temperature $T_c$ variations agree with the insulator to metal variations, Tt was determined from transport measurements.

**Papers published:**1). J. Solid State Chemistry 174 (2003) 198; 2) Phys. Rev. B. (in press); 3) Science and Technology of advanced materials 4 (2003) 149. Three papers were presented at international conferences. Two invited seminars were given by the CI (Wang).

## 2. Progress Report on ARC Fellowships

***Optimization of thermal- and mechanical processing and critical current density of high $T_c$ superconducting Ag-clad Bi(Pb)SrCaCuO tapes***

**Senior Research Fellowship Project**

| | | | | | |
|---|---|---|---|---|---|
| **Funded:** | 1999 | 2000 | 2001 | 2002 | 2003 |
| **Project ID:** | F89905267 | | | | |
| **Chief Investigator:** | H.K. Liu | | | | |

**The micro- and the mesotexture were analysed using electron backscattered diffraction in the transverse direction of Bi2223 tapes**. Microtexture and mesotexture of PIT processed Bi2223 tapes were characterized using angle-axis pairs and Rodrigues - Frank (RF) vectors. The results of microtexture evaluation indicates that a/b axes texture did exist in PIT processed tapes while the mesotexture RF plot exhibits that majority of the grain boundaries were formed by grains with non-parallel c-axis. These grain boundaries generally had low mismatch angles of up to $10^o$. High-angle misorientation boundaries ranging up $45^o$ were generally associated with c-axis twist boundaries. The dominating misorientation angle for both sample sides and centre was found to be $4^o$. It is believed that the micro- and mesotexture distribution characteristics have influence over the Jc distribution in the transverse direction of Bi2223 tapes.

**The effect of various sintering conditions on the phase transformation and critical current density of multifilament Bi-2223 tapes with AgMg sheaths has been investigated.** We have found that the conversion from Bi-2212 phase to Bi-2223 phase is significantly influenced by the sintering atmosphere of the first heat treatment. Sintering in air tended to produce large 2223 grains and a higher degree of texturing compared to sintering in lower oxygen pressure (7.5%). The lower partial pressure of oxygen promoted faster and more complete conversion of 2212 and smaller Bi-2223 grain size. We also observed that conditions of the second heat treatment had less of an impact on the conversion of Bi-2212 phase but influenced the proportion and size of secondary phases, especially influenced that of the lead-rich secondary phase.

**The performance of AgMg Bi-2223 tapes has been significantly improved by using optimized condition.** The engineering critical current density ($J_e$) over 8,000 A/cm$^2$ in 20 m lengths and $J_e$ over 6,000 A/cm$^2$, critical current density ($J_c$) over $3\times10^4$ A/cm$^2$ in 200 m long PIT (powder in tube) tapes can be produced. The critical current ($I_c$) up to 80 A, Je over The short rolled tapes 13,000 A/cm$^2$ and $J_c$ over 52,000 A/cm$^2$ have been achieved.

**Ag, AgAu7wt%, AgSb0.6wt% and AgMg0.2wt% alloys were used as precursor and restack sheath materials** for fabricating 37-filament Bi-2223 tapes using a PIT technique with a two-stage heat treatment process. Analysis of the $I_c$ and volume fractions of the Bi-2223, Bi-2212, Bi-2201 and Bi-3221 phases indicated that volume fractions of Bi-2223>90%, Bi-2212 ~ 5%, Bi-2201 ~ 0% and Bi-3221 < 2% normally result in tapes with the highest $I_c$. The relationship between Jc and magnetic field was characteristic of multifilamentary 2223 tapes fabricated using a PIT technique. No conclusive correlation between alloy type or configuration and Ic performance in field was found. The sequence of the sheath hardness and tensile strength from highest to lowest was AgMg0.2wt%, AgSb0.6wt%, AgAu7wt% or Ag corresponding to the ranking of bend strain tolerance.

**Local magnetic flux distribution in a superconducting core of Bi-2223 tape has been investigated** above and below a characteristic field B*, which is defined by global critical current density $J_c$ measurements. Below this field, $J_c$ as a function of applied magnetic field $B_a$ exhibits a $B_a$-independent plateau often referred to the single vortex pinning regime. Below B* the flux distribution within the core does not change. Furthermore, the strong B* (T) dependence is suggested to be due to thermally activated depinning of individual vortices.

9 papers from this project were published in 2003.

## 3. Progress Report on SPIRT/Linkage Programs

***Solid-state rechargeable lithium batteries for telecommunication and portable electronic devices***

| | |
|---|---|
| **Funded:** | 2001 2002 2003 |
| **Project ID:** | C00107603 |
| **Chief Investigators:** | G.X. Wang, H.K. Liu, D.H. Bradhurst |
| **Assoc. Investigator:** | X.Q. Yang |
| **Industry Partners:** | Australian Battery Technology, Lexel Battery Ltd. |

Several novel anode materials have been investigated. The electrochemical chemical properties of graphitized mesocarbon microbeads (MCMB) were systematically evaluated via a variety of electrochemical techniques. MCMB carbon is a well-graphitized carbon. Cyclic voltammograms show only one reduction peak and one oxidation peak, which correspond to lithium ion intercalation and de-intercalation, respectively. The MCMB anodes have a stable lithium intercalation capacity of 325 mAh/g on high-rate charge-discharge cycling. The kinetics of $Li^+$ ion insertion in the MCMB host have been characterized by ac impedance measurements. In the lower potential range, the charge-transfer resistance of the MCMB electrode is independent of the state of lithiation. A series of Sn–graphite composites were prepared by electroless chemical deposition. EDS and XRD analysis confirmed presence of Sn in the graphite structure. Cyclic voltammetry measurement shows extra reduction and oxidation peaks, which are related to the formations of $Li_xSn$ alloys. Sn–graphite composite electrodes demonstrated a much higher lithium storage capacity than that of bare graphite electrode. Due to the nature of nanosize encapsulated Sn particles in ductile graphite structure, Sn–graphite composite electrodes have shown reasonably good cyclability on cycling. $LiTi_2(PO_4)_3$ with NASICON-type structure was prepared by a two-step solid-state reaction. X-ray diffraction confirms $LiTi_2(PO_4)_3$ compound having a NASICON structure: rhombohedral. Electrochemical measurements have shown that lithium can be electrochemically inserted into $LiTi_2(PO_4)_3$ structure with a maximum intake of 5.2 moles of lithium per mole of $LiTi_2(PO_4)_3$ compound and $[PO_4]$ tetrahedra could participate in the redox reaction. This corresponds to a lithium storage capacity of 360 mAh/g. The kinetic parameters of Li insertion in $LiTi_2(PO_4)_3$ NASICON were determined by an a. c. impedance technique. The charge transfer resistance ($R_{CT}$) and exchange current density ($i_o$) were invariable regardless of the state of Li insertion, which is associated with the unique structure characteristics of the NASICON skeleton. However, the Li diffusion coefficient $D_{Li}$ was found to vary with the state of Li insertion. $D_{Li}$ is in the range $1.4\times 10^{-11}$ to $1.2\times 10^{-9}$ $m^2/s$, which is much higher than for other intercalation materials.

Several multiple ions doped lithium nickel oxides with a formula of $LiMn_xCr_yNi_{1-x-y}O_2$ were synthesized via solid-state reaction at high temperature. These phase pure $LiMn_xCr_yNi_{1-x-y}O_2$ compounds have a layered hexagonal structure. Electrochemical properties of these $LiMn_xCr_yNi_{1-x-y}O_2$ compounds were systematically investigated. Typical $LiMn_xCr_yNi_{1-x-y}O_2$ cathodes can deliver a capacity in the range of 140-180 mAh/g with fairly stable cyclability. The kinetics of lithium insertion in these cathodes were characterized via a.c. impedance measurements. These newly developed $LiMn_xCr_yNi_{1-x-y}O_2$ compounds show some great promises as cathode materials for lithium-ion batteries in the future with low cost and less toxicity.


- Jane Yao, G.X. Wang, Jung-ho Ahn, H.K. Liu, S.X. Dou, "Electrochemical studies of graphitised mesocarbon microbeads as an anode in lithium-ion cells" J. Power Sources **114** (2003) 292-297 (Communication).
- J.-H. Ahn, G. X. Wang, H.K. Liu, SX Dou, "Nanoparticle dispersed PEO polymer electrolytes for Li batteries, J. Power Sources **119 – 121** (2003) 422 - 426.
- G.X. Wang, Jung-ho Ahn, Jane Yao, Matthew Lindsay, H.K. Liu, S.X. Dou, "Preparation and characterisation of carbon nanotubes for energy storage" J. Power Sources **119-121** (2003) 16 – 23.
- G.X. Wang, Steve Bewlay , Jane Yao, Y. Chen, Z. P. Guo, H.K. Liu and S.X. Dou "Multiple-ion-doped lithium nickel oxides as cathode materials for lithium-ion batteries" J. Power Sources **119-121** (2003) 189 -194.
- G.X. Wang, D.H. Bradhurst, S.X. Dou, HK Liu, "$LiTi_2(PO_4)_3$ with NASICON-type structure as lithium-storage materials" J. Power Sources **124** (2003) 231-236 (Communication).
- G.X. Wang, Jane Yao, Jung-ho Ahn, H.K. Liu and S.X. Dou, "Electrochemical properties of nanosize Sn-coated graphite anodes in lithium-ion cells" Journal of Applied Electrochemistry, **34** (2004) 187 – 190.

*Fabrication and Characterisation Diboride Superconducting Wires*

**Funded:** 2002 2003 2004
**Project ID:** P0219629
**Chief Investigator:** S.X. Dou, X.L. Wang, M. Ionescu
**Partner Investigator:** M. Sumption
**Industry partners:** Hyper Tech Research Inc. OH USA, Alphatech International Ltd. Sydney

The aim of the proposed project is to investigate the fabricability and properties of $MgB_2$ superconducting wires using a number of processing techniques established in previous low temperature and high temperature superconductors. The expected outcome is to have a $MgB_2$ conductor that has a higher performance in magnetic fields than niobium-titanium (NbTi) alloy, a higher operating temperature (up to 20K), and a lower cost than current commercial NbTi wire.

**Fabrication of Long Cu sheathed Wires:** We reported the results of transport $J_c$ of solenoid coils upto 100 turns fabricated with Cu-sheathed $MgB_2$ wires using a wind-reaction in-situ technique. Solenoid coils with diameter as small as 10 mm can be readily fabricated using a wind-reaction in-situ technique. The $J_c$ of coils is essentially the same as in the form of straight wires. A $J_c$ of 133,000 A/cm$^2$ and 125,000 A/cm$^2$ at 4K and self field has been achieved for a small coil wound using Cu-sheathed tape and Cu-sheathed wire respectively. These results indicate that the $MgB_2$ wires have a great potential for lage scale applications.

**Properties of superconducting $MgB_2$ wires: ``in-situ'' versus ``ex-situ'' reaction technique:** We have fabricated a series of iron-sheathed superconducting wires by the powder-in-tube technique. It turned out that ``ex-situ'' prepared wire has considerable disadvantages compared to the in-situ wires. As a result, higher critical current densities Jc were measured over the entire range of applied magnetic fields for all the samples. Pinning of vortices in $MgB_2$ wires is shown to be due to grain boundaries. Jc behavior is governed by an interplay between the transparency of grain boundaries and the amount of ``pinning'' grain boundaries. Differences between thermo-magnetic flux-jump instabilities in the samples and a possible threat to practical applications are also discussed.

**Nano-Carbon Tube Doping**: Effect of doping of carbon nano-tubes on transition temperature, lattice parameters, critical current density and flux pinning were studied for $MgB_{2-x}C_x$. The carbon substitution for B was found to enhance $J_c$ in magnetic fields but depress $T_c$. By controlling the extent of the substitution and addition of carbon nano-tubes we can achieve the optimal improvement on critical current density and flux pinning in magnetic fields while maintaining the minimum reduction in $T_c$. Under these conditions, $J_c$ was enhanced by two orders of magnitude at 8T and 5K and 7T and 10K. $J_c$ was more than 10,000A/cm$^2$ at 20K and 4T and 5K and 8.5T respectively.

**The Effect of Sample Size:** A strong effect of sample size on magnetic $J_c(H)$ was observed for bulk $MgB_2$. $J_c$ decreased by more than 100 times at 7T and 5K, when the sample dimensions decreased from 7.15*3.27*1.07mm$^3$ to 1.87*0.85*0.29mm$^3$. At the same time, zero-field $J_c$ increased with decreasing sample size. A comparison of magnetic $J_c(H)$ for samples of different size could lead to misleading conclusions if the samples are smaller than a few millimetres. The $J_c(H)$ determined by transport measurements is reliable because the sample is above this size. Different coupling between the superconducting grains at different length scales is proposed for the explanation of these results.

**S.X. Dou**, W.K. Yeon, J. Horvat, and M. Ionescu, "Effect of carbon nanotube doping on critical current density of MgB2 superconductor", *Appl. Phys. Lett.* **83,** 4996-4998 (2003)

**S.X. Dou**, J. Horvat, S. Soltanian, X.L. Wang, M.J. Qin, S.H. Zhou, H.K. Liu and P.G. Munroe "Transport critical current density in Fe-sheathed nano-SiC doped $MgB_2$ Wires" *IEEE Trans. On Appl. Supercond.* **13, 2** 3199-3202 (2003)

A.V. Pan, S. Zhou, H.K. Liu, and S.X. Dou, "Properties of superconducting $MgB_2$ wires: in-situ versus ex-situ method", Supercond. Sci. Technolo. **16**, 639-644 (2003)

S. Soltanian, J. Horvat, X.L. Wang, M. Tomsic and **S.X. Dou** "Transport critical current of solenoidal $MgB_2$/Cu coils fabricated using a wind-reaction in situ technique" *Supercond. Sci. Technol.* **16**, **1**, L4-L6 (2003)

***Developing new cathode materials for Li-ion batteries using Australian mineral resources***

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|---|---|---|---|
| **Funded:** | 2002 | 2003 | 2004 |
| **Project ID:** | LP0214179 | | |
| **Chief Investigator:** | S.X. Dou | | |
| **Assoc. Investigator:** | G.X. Wang, J.Y. Lee, S.J. Kennedy | | |
| **Industry Partners:** | Sons of Gwalia, OM Group | | |

The proposal will bring together expertise in materials processing, structure characterisation and electrochemistry to carry out collaborative research on cathode materials for lithium ion batteries. The major objective of this proposed project is to develop technologies for preparing advanced cathode materials used in rechargeable lithium-ion batteries.

The spray pyrolysis method has been successfully used for in-situ preparation of nano-structured $LiCoO_2$ and starting nano-oxides (CoO, $Co_3O_4$ and NiO) for the use of $LiNi_xCo_{1-x}O_2$ cathode materials. The in-situ process has significant advantage for industrial application because of its scalability, technological simplicity, and potential low cost production: (i) production of spherical nano-structured $LiCoO_2$ powder with specific surface area 15 times higher than the commercial powders using Australian chemicals, (ii) in-situ production of nano-structured Co oxides (CoO and $Co_3O_4$), with controlled specific surface area and crystal size between 2-15 nm. These materials are highly reactive and suitable for fast sintering of $LiCoO_2$ phase, reducing the sintering time and temperature and production costs. The produced cobalt oxides have also other promising application as catalysts because their surface area could overcome the surface area of conventionally prepared powders several times. (iii) Nano-structured NiO powders with crystal size 3-8 nm were also prepared. This material can be used as a highly reactive precursor for synthesis of $LiNi_xCo_{1-x}O_2$ cathode materials.

Single-phase electroactive $LiCo_xMn_yNi_{1-x-y}O_2$ compounds were obtained from lithium compounds and the precursor $Co_xMn_yNi_{1-x-y}(OH)_2$ by heating in air at 850 – 900 °C. The precursor $Co_xMn_yNi_{1-x-y}(OH)_2$ was obtained by the chemical co-precipitation method. The synthesized $LiCo_xMn_yNi_{1-x-y}O_2$ has good morphology and uniform particle size distribution. $LiCo_{0.1}Mn_{0.2}Ni_{0.7}O_2$ and $LiCo_{0.2}Mn_{0.2}Ni_{0.6}O_2$ had the best electrochemical characteristics and their initial capacities can reach 150 mAh/g. Orthorhombic $LiMnO_2$ was synthesized via the sol-gel process using citric acid as chelating agent. XRD revealed that the samples with a high molar ratio R (R=1, 2) contain an MnO impurity phase, which is electrochemically inactive. The sample with low R (R=0.5) exhibited a high initial capacity, above 190 mAh/g.

Carbon-included lithium iron phosphate powders were successfully synthesised by a spray pyrolysis method with a short final amelioration sintering. The measurements suggest that adding sucrose to produce carbon in $LiFePO_4$ materials can yield controllable, monotonic increases in conductivity of the final pellets spanning 7 orders of magnitude across the range 0 - 31 wt% C. This is comparable to the 8-order-of-magnitude increase in conductivity by doping $LiFePO_4$ with metals supervalent to lithium, and also eliminates the need to hand-mix in carbon-black when preparing Li-ion battery cathode powders. Cyclic voltametry shows strong redox reaction peaks. The charge/discharge tests demonstrated a flat charging and discharging plateau, but the capacity and overall electrochemical properties need further improvement.

K. Konstantinov, G. X. Wang, J. Yao, H. K. Liu and S. X. Dou, Stoichiometry controlled high performance $LiCoO_2$ electrode materials prepared by a spray solution technique, Journal of Power Sources **119-121** (2003) 195-200.

K. Konstantinov, J. Wang, S. Bewlay, G. X. Wang, H. K. Liu and S. X. Dou, Spray pyrolysis technique for fabrication of nano-sized spherical agglomerated oxide powders for batteries, J. Metastable and Nanocrystalline Mater. **15-16** (2003) 325.

Yao Chen, G.X. Wang, K. Konstantinov, H.K. Liu, S.X. Dou, "Synthesis and characterisation of $LiCo_xMn_yNi_{1-x-y}O_2$ as a cathode materials for secondary lithium batteries" J. Power Sources 119-121 (2003) 184 - 188.

Z. Guo, K. Konstantinov, G.X. Wang, H.K. Liu and S.X. Dou, "Preparation of orthorhombic $LiMnO_2$ material via sol-gel process" J. Power Sources 119-121 (2003) 221 - 225.

***Fabrication of Magnesium Diboride ($MgB_2$) thick films***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $22,545 | $22,545 | $22,545 |
| **Total funding:** | **$67,635** | | |
| **Project ID:** | LP0228370 | | |
| **Chief Investigator:** | Dr X L Wang | | |
| **APA(I) Award(s):** | Q.W. Yao | | |
| **Industry Partner(s):** | SFC Enterprises Pty Ltd | | |

This project proceeded well according to the plan. High performance $MgB_2$ thick films were fabricated on various substrates and well characterized.

1. Pure and doped $MgB_2$ thick films were fabricated on Ni substrates by applying a coating mixture of powders of elemental magnesium and boron with varying amounts of elemental Cu and nano-SiC powders, followed by a high pressure press, and sintering at 840 $^oC$ or 900 $^oC$ for just a few minutes, and then quenching in liquid nitrogen. For films sintered at 900 $^oC$, critical current densities $J_c$ were achieved as high as $1.4 \times 10^6$ A/cm$^2$ at 20 K and $2.3 \times 10^5$ A/cm$^2$ at 20 K and 2 T for the pure and SiC added films. Films doped with 5 wt% of Cu powders were observed to have better adherence to the Ni substrate without degradation in $T_c$, and $J_c$ was found to be slightly decreased, but still remains as high as $7 \times 10^5$ A/cm$^2$ at 20 K in zero field. It was observed that $J_c$ and the irreversibility field increase with an increasing sintering temperature up to 900 $^oC$. Furthermore, nano-SiC addition has significantly improved the irreversibility field compared to un-doped $MgB_2$ films.

2. Polycrystalline $MgB_2$ thick film samples with 0, 5, 10, and 20wt % nano-Y-$ZrO_2$ (YSZ) powder addition were prepared by a short sintering, for as little as several minutesand also by long sintering in-situ reaction processes. The phases, microstructures, and flux pinning were characterized by XRD, SEM, TEM and magnetic measurements. TEM and EDS analysis indicated that nano-YSZ particles were included in $MgB_2$ grains. XRD results showed that YSZ does not react with $MgB_2$. Furthermore, the transition temperature of the YSZ nano-particle doped samples dropped by about 3 K compared to the comparable un-doped samples. Samples doped with YSZ powders showed a higher critical current density in low magnetic fields, however, the $J_c$ drops faster compared to samples made by the long sintering process. It is proposed that the improved $J_c$ in low fields was due to the enhanced density of the sample, which was caused by the YSZ nano-particle inclusions.

3. Using thick film fabrication techniques, pure and 10 wt % nano-SiC doped $MgB_2$/Cu coated tapes were fabricated using a coating and pressing method. Samples were sintered using an in-situ reaction process. It was observed that the nano-SiC doped tapes were significantly reacted with the Cu sheath at 700 $^oC$, while pure samples had less reaction with Cu under the same conditions. However, for sintering at 667 $^o$ C for just 6 minutes, the reaction with Cu was significantly reduced for the nano-SiC doped samples, and this led to very high critical current densities of more than 1 MA/cm$^2$ in zero field at $T \leq 10$ K. The $J_c$ values exceed $10^5$ A/cm$^2$ for 30 K in zero field, 20 K in 2 T, and $T \leq 10$ K in 4 T. These $J_c$ values are of one to two orders of magnitude higher than those of the pure $MgB_2$/Cu short tapes and the best reported $J_c$ values for Cu sheathed wires and tapes, and are comparable to the $J_c$ values reported for $MgB_2$/Fe tapes. These nano-SiC doped $MgB_2$ /Cu tapes also exhibited very small flux jumping at 5 K. Such a high $J_c$ value and its field performance together with possible high thermal stability make the Cu-sheathed $MgB_2$ tapes an attractive candidate for large-scale applications.

   Papers published: 1.Physica C 402 (2004) 38-44; 2). Supercond. Sci. Technol. **17** (2004) L21. . Two more papers are to be published in International Journal of Nanoscience and Journal of Ceramics International. Four papers were presented as oral or poster presentations at two international conferences, M2-HTSC and ICMAT

***Thermionic cooling for domestic refrigeration , Project ID: C00106566***

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|---|---|---|---|
| **Funded:** | 2001 | 2002 | 2003 |
| **Chief Investigator:** | R.A. Lewis, C. Zhang | | |
| **Industry Partner:** | Email Limited | | |
| **Postgrad. Students:** | Zhijian Dou | | |

Further device simulations were carried out. Thermal conductivity in layered systems were studied in detail taking into account the scattering at boundaries. We have started analytical and simulation work on a new system which combines the thermionic emission and radiation recombination to achieve the maximum power output. Selective thermal and optical measurements on the second generation heterostructure were performed to determine the temperature distribution on various electrodes.

## 4. Reports on IREX Project of International Fellowships in 2003

***Composite cathode materials for lithium ion battery using chemical coating technique***

**Project ID:** LX0214959
**Funded:** 2002
**Chief Investigator:** S.X. Dou
**International Fellow:** J.Y. Lee

The aim of this project is to develop new composite cathode materials ($LiCoO_2$ coated $LiM_xMn_{1-x}O_2$) using a chemical coating process in order to improve the electrochemical properties such as the cyclic property at elevated temperature and the rate capability. The expected outcome is a new cathode material which has high-energy capacity, long cycle life and low cost.

Based on our previous experiences the base line materials, layered $LiMn_2O_4$ and $LiCoO_2$ were prepared and characterised separately. The $LiCoO_2$-coating solution was prepared by a chemical process and $LiCoO_2$ coated composite was obtained. For structural analysis of the coated lithium manganese oxide, samples were characterized with x-ray diffraction (XRD) and transmission electron microscopy (TEM). It was found the composite consisted of two phases. Preliminary results show a noticeable improvement in the rate capacity of the $LiMn_2O_4$ after surface coating with $LiCoO_2$.. The coating plays an important role in improvement of activation processes for the Li absorption and desorption.

A further study is performed in order to improve the high temperature performance and rate capability of $LiMn_2O_4$ for cathode material of lithium secondary batteries by coating the surface of $LiMn_2O_4$ with $LiNi_{1-x}Co_xO_4$. We developed a coating process which can coat the surface of $LiMn_2O_4$ with $LiNi_{1-x}Co_xO_4$ particles successfully. The capacity retention for the coated $LiMn_2O_4$ after the high temperature storage at 65$^o$C for 300 h showed no capacity loss. The high temperature cyclic property increased 92% at 100 cycles. The improvement of high temperature property of LiNi1-XCoXO2-coated LiMn2O4 can be attributed to the suppression of electrolyte decomposition on the surface of $LiMn_2O_4$ and the restraint of Mn dissolution which result from encapsulating the surface of $LiMn_2O_4$ with $LiNi_{1-x}Co_xO_4$. The rate capability of LiMn2O4 is also improved by coating its surface, owing to the suppression of 1st arc and 2nd arc in EIS data which result from the decrease of surface film as an insulating layer and higher electrical conductivity of $LiNi_{1-x}Co_xO_4$.

On another topic, by substituting Fe for Ni, the rate capability and the cyclic property of $LiNi_{0.8}Co_{0.2}O_2$ is improved. The improved rate capability is attributed to the increase of c-axis lattice and the decrease of lattice contraction during charging. The improved cyclic property of $LiNi_{0.8}Co_{0.2}O_2$ is attributed to relieving the stress induced by lattice expansion.

Prof Lee gave a series of five lectures on the proposed topics to our staff and postgraduate students during this period. We found these lectures to be very informative and educational to staff and postgraduate students.


1. M.S. Song, S.C. Ham, H.S. Kim, J.H. Kim, K.T. Kim, Y.M. Kang, H.J. Ahn, **S.X. Dou** and J.Y. Lee, "Effects of nanosized adsorbing material on electrochemical properties of S cathodes for Li/S secondary batteries", *J. Electrochem. Soc.*, 151 (2004) A791-A795
2. Yong-Mook Kang, Ki-Tae Kim, Jin-Ho Kim, Min-Sang Song, Jai-Young Lee, H.K.Liu and **S.X.Dou**, "A Study on the Charge-Discharge Mechanism of $Co_3O_4$ as an Anode for the Li Ion Secondary Battery", *J.Electrochem. Soc.* in press (2004)
3. Yong-Mook Kang, Ki-Tae Kim, Jin-Ho Kim, Hyun-Seok Kim, Paul S. Lee, Jai-Young Lee, H..K.Liu and **S.X.Dou**, "Electrochemical propertiesbehaviors and morphology of $Co_3O_4$, Ni–$Co_3O_4$ mixture and Ni–$Co_3O_4$ composite as anode materials for Li ion secondary batteries", *Journal of Power Sources,*in press(2004)
4. Sung-Chul Park, Ki-Tae Kim, H.K. Liu, **S.X. Dou** and Jai-Young Lee, "Improvement of Thermal Decomposition Property of Cell Using $LiCoO_2$ by Surface Coating with $LiMn_2O_4$", *Electrochemical and Solid-State Letters, submitted.*
5. Ki-Tae Kim, Sung-Chul Park, H.K. Liu, **S.X. Dou**, and Jai-Yung Lee, "Electrochemical Performance of Sn-Co(-C) Prepared by Mechanical Alloying as Anode Material for Li-Ion Batteries", *Journal of Power Source, submitted..*

***Investigation of a series of metallic substrate materials suitable for developing long Y-Ba-Cu-O superconductors***

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|---|---|---|---|
| **Funded:** | 2002 | 2003 | 2004 |
| **Project ID:** | LX0211084 | | |
| **Australian Investigator:** | H.K. Liu | | |
| **Partner Investigator:** | D.L. Shi | | |

Aims: Researchers from Institute for Superconducting and Electronic Materials, the University of Wollongong (UoW) & the Dept. Mat. Sci. & Eng., University of Cincinnati (UC) in USA will build strong collaborations through the joint research on a series of metallic substrate materials. Significance: the research work will contribute to develop the second generation of high temperature superconducting wire technology. Expected outcomes: strengthen international research experience for junior researchers and develop new collaborations between senior researchers from UoW in Australia and UC in USA.

Two persons from UC visited the University of Wollongong from 20$^{th}$ August to 10$^{th}$ September (2003) and 4$^{th}$ Feb to 14$^{th}$ Feb (2004). They gave two seminars related with the synthesis and transport properties of YBCO thin films deposited by a fluorine-free solution method during his two visiting periods. Prof. Shi (UC), Prof. Liu (UoW), Dr. M. Ionescu (UoW), A. Li (PhD candidate, UoW) and Y. Zhao (PhD candidate, UoW) have worked together for YBCO thin films using pulsed laser deposition technique and discussed the collaboration project for few times. Prof. Shi's two PhD students (Y. Xu and HB Yao) also communicated with the researchers at the UoW.

In 2002 and 2003, the researchers from University of Wollongong (UoW) and the University of Cincinnati (UoC) together have worked together on the buffer layer and textured metal for YBCO thick and thin films. Based on the time and temperature relationship, the suitable substrate materials have been chosen. Two papers have been presented at the International conferences and the refereed full written papers are reviewed by the experts. In 2004 students and research fellows from UoW will visit the UC and will continue to develop the well-textured Y-123 thin and thick films.

Despite great success in the TFA methods of depositing $YBa_2Cu_3O_x$ (YBCO) thin films for coated conductors, critical issues involved in removing $BaCO_3$ have not entirely been settled. There could be other possible ways of dealing with carbon that remains in the film. We have recently developed a fluorine-free sol-gel synthesis with several important advantages including precursor solution stability, improved film density, and elimination of HF during processing. With this new approach, high quality YBCO films have been developed on single crystal substrates with the transport $J_c$'s up to $10^6$A/cm$^2$. In this study, the precursor solution stoichiometry was altered and its effects on superconducting properties were studied. The fluorine-free Sol-gel-derived films on the $LaAlO_3$ (LAO) substrate exhibited epitaxial growth with excellent in- and out-plane texture. Experimental details are reported on the sol-gel synthesis chemistry and XRD and TEM characterization of the YBCO thin films. Also discussed is the underlying formation mechanism of the YBCO phase during the synthesis.

Donglu Shi and Yongli Xu Aihua Li, Michal Ionescu, Hua Kun Liu, S.X. Dou, Haibo Yao and Z. Han "Synthesis and characterization of epitaxial YBCO thin films prepared by a fluorine-free sol-gel method for coated conductors", presented at ICMC topical workshop and to be published in Supercond. Science and Technology

A.H. Li, M. Ionescu, H.K. Liu, D.L. Shi and S.X. Dou, "Microstructure and phase evolution in $Yba_2Cu_3O_y$ films grown on various substrates fabricated via a non-fluorine sol-gel route", presented at ICMC topical workshop.

# Selected Abstracts

***Tin-based composite materials as anode materials for Li-ion batteries***, J. Power Sources **119-121**, 45-49 (2003)

**J.H. Ahn, G.X. Wang, H.K. Liu and S.X. Dou**

Tin, tin oxide and NiSn-based nanocomposites with Al2O3 dispersion were prepared by ball milling to see their electrochemical properties as a new anode material for lithium-ion batteries. Electrochemical tests demonstrated that the initial charge–discharge capacities are very high for these materials. However, the capacity faded rapidly after the first cycle due to irreversible reactions. This is thought to be caused by the separation of the active materials from the inert oxide particles. The initial cycling efficiency was markedly improved by subsequent annealingof the ball-milled electrode.

***Nanoparticle-dispersed PEO polymer electrolytes for Li batteries***, J. Power Sources **119-121**, 422-426 (2003)

**J.H. Ahn, G.X. Wang, H.K. Liu and S.X. Dou**

Nanoparticle-dispersed polymer electrolytes have been prepared by stirring or high-energy ball milling of polyethylene oxide (PEO), lithium salt (LiCF3SO3, LiClO4 and LiPF6), and nanometer-size ceramic powder (TiO2, SiO2 and Al2O3). The smaller the size of ceramic particles, the better they influence the crystallization kinetics of the PEO polymer chains. High-energy ball milling lowers the glass transition temperature of the composite polymers, and thus increases the ionic conductivity greater than the order of the magnitude compared with the un-milled samples. The highest ionic conductivity was reported when using LiPF6 as added lithium salt and Al2O3 as dispersed particle. Cyclic voltametric measurements showed that the PEO-system is electrochemically stable in the range of 2–5

*Up-conversion luminescence of ytterbium and thulium co-doped potassium yttrium double tungstate crystal [for potassium read sodium],* Crystal Research & Technology, vol.37, no.12, 2002, pp.1318-24. Publisher: Wiley-VCH Verlag Berlin GmbH, Germany.

**Z.X. Cheng, X.J. Han, H.C. Chen, X.L. Wang, H.K. Liu, S.X. Dou, F. Song and H.C. Guo**

Thulium and ytterbium co-doped double tungstate Yb3+,Tm3+:NaY(WO4)2 ingle crystals were prepared by using RF-heating Czochralski (CZ) pulling method. Its polarized transmittance spectra have been recorded in the region of 290-2000 nm at room temperature. The energy levels transitions were assigned to the corresponding absorption line. The up-conversion luminescence at 793 nm and 475 nm were measured when the sample were pumped by 972 nm LD and the energy transfer mechanism between Yb3+and Tm3+/ ions was analyzed. (7 References).

***High $T_c$ conductor processing techniques*,** Handbook of Superconducting Materials, pp421-448, ed by D. Cardwell, University of Cambridge, UK, D. Ginley, NREL, USA, IoP (2003)

**S.X. Dou**

This chapter presnts a comprehensive review on the Bi-based HTS conductor processing technique, including powder processing, effect of precursor powder composition, various powder preparation methods and effect of carbon in the starting materials. For mechanical deformation, it include Powder-In-Tube Technique, cold deformation process, sandwich rolling, four axis rolling, cryogenic deformation, hot deformation and eccentric rolling and sequential pressing. Various thermal treatments and their effect on phase evolution are discussed. Some special processing techniques are also covered including continuous tube filling and forming process, doctor-blade or dip-coating technique, selection of sheath materials and resistive interfilamentary barriers for reducing ac loss.

*Superconductivity, critical current density, and flux pinning in $MgB_{2-x}(SiC)_{x/2}$ superconductor after SiC nano-particle doping*, J. Appl. Phys. 94, pp. 1850-1856 (2003)

**S. X. Dou, A. V. Pan, S. Zhou, M. Ionescu, X. L. Wang, J. Horvat, H. K. Liu, and P. R. Munroe**

We investigated the effect of SiC nanoparticle doping on the crystal lattice structure, critical temperature $Tc$ , critical current density $J_c$ , and flux pinning in $MgB_2$ superconductor. A series of $MgB_{2-x}(SiC)_{x/2}$ samples with $x$= 0 – 1.0 were fabricated using an *in situ* reaction process. The contraction of the lattice and depression of $T_c$ with increasing SiC doping level remained rather small most likely due to the counterbalancing effect of Si and C co-doping. The high level Si and C co-doping allowed the creation of intragrain defects and highly dispersed nanoinclusions within the grains which can act as effective pinning centers for vortices, improving $J_c$ behavior as a function of the applied magnetic field. The enhanced pinning is mainly attributable to the substitution-induced defects and local structure fluctuations within grains. A pinning mechanism is proposed to account for different contributions of different defects in $MgB_{2-x}(SiC)_{x/2}$ superconductors.

***Effect of carbon nano-tube doping on critical current density of $MgB_2$ superconductor,*** Appl. Phys. Lett. 83 4996-4998 (2003)

**S.X. Dou, W.K. Yeoh, J. Horvat and M. Ionescu**

Effect of doping of carbon nano-tubes on transition temperature, lattice parameters, critical current density and flux pinning were studied for $MgB_{2-x}C_x$ with x = 0, 0.05, 0.1, 0.2 and 0.3. The carbon substitution for B was found to enhance $J_c$ in magnetic fields but depress $T_c$. The depression of $T_c$, which is caused by the carbon substitution for B, increases with increasing doping level, sintering temperature and duration. By controlling the extent of the substitution and addition of carbon nano-tubes we can achieve the optimal improvement on critical current density and flux pinning in magnetic fields while maintaining the minimum reduction in $T_c$. Under these conditions, $J_c$ was enhanced by two orders of magnitude at 8T and 5K and 7T and 10K. $J_c$ was more than 10,000A/cm$^2$ at 20K and 4T and 5K and 8.5T respectively.

***Transport critical current density in Fe-sheathed nano-SiC doped $MgB_2$ wires,*** IEEE Trans. OnAppl. Supercond. 13, 3199-3202 (2003)

**S.X. Dou, J. Horvat, S. Soltanian, X. L. Wang, M.J. Qin, S.H. Zhou, H.K. Liu and P.G. Munroe**

The nano-SiC doped $MgB_2$/Fe wires were fabricated using a powder-in-tube method and an in-situ reaction process. The depression of $T_c$ with increasing SiC doping level remained rather small due to the counterbalanced effect of Si and C co-doping. The high level SiC co-doping allowed creation of the intra-grain defects and nano-inclusions, which act as effective pinning centers, resulting in a substantial enhancement in the $J_c(H)$ performance. The transport $J_c$ for all the wires is comparable to the magnetic $J_c$ at higher fields despite the low density of the samples and percolative nature of current. The transport $I_c$ for the 10wt% SiC doped $MgB_2$/Fe reached 660A at 5K and 4.5T ($J_c$ = 133,000A/cm$^2$) and 540A at 20K and 2T ($J_c$ = 108,000A/cm$^2$). The transport $J_c$ for the 10wt% SiC doped $MgB_2$ wire is more than an order of magnitude higher than for the state-the-art Fe-sheathed $MgB_2$ wire reported to date at 5K and 10T and 20K and 5T respectively. There is a plenty of room for further improvement in $J_c$ as the density of the current samples is only 50%.

***Induced charge density oscillation under a quantizing magnetic field and an intense terahertz radiation*** Phys. Rev. B67, 075105 (2003)

**M. Fujita, T. Toyoda, J. Cao, and C. Zhang**

The time-dependent Schrodinger equation for a two dimensional electron gas in a strong magnetic field and an intense terahertz laser field is solved by constructing unitary transformations. We calculate the charge density fluctuation under a weak probing potential. It is found that the induced charge density oscillates rapidly in time with two characteristic frequencies, the cyclotron frequency and the laser frequency.

***Manganese-ion Doped Layered Nanocrystalline Li-Co-Mn-O powders prepared From Sol-Gel Processing,*** Journal of Nanocrystallize & Metastable Materials, 15-16,727(2003)

**Z.P. Guo, J.H. Ahn, H.K. Liu, S.X. Dou**

The nanocrystalline lithium-rich cobalt manganese oxide $Li(Co_{1-x}Li_{x/3}Mn_{2x/3})O_2$ (0<x<1) powder has been successfully prepared by a sol-gel method. The structure can be understood as a solid solution of layered $LiCoO_2$ and $Li_2MnO_3$. Compared with samples prepared by solid-state reaction, the particles of sol-gel samples are fine and homogeneous, the discharge capacities are much larger and the discharge profiles are quite different. The XRD patterns and discharge curves for samples with high "x" are similar to that of monoclinic lithium manganese oxides. All samples showed a good cycleability, but the rechargeable capacity decreased with the increase of the amount of Mn and Li introduced by the replacement of Co.

***Preparation of orthorhombic $LiMnO_2$ material via the sol-gel processs,*** J. Power Sources **119-121**, 221-225 (2003)

**Z.P. Guo, K. Konstantinov, G.X. Wang, H.K. Liu and S.X. Dou**

Orthorhombic $LiMnO_2$ was synthesized via the sol–gel process using citric acid as a chelating agent. The effect of varying the molar acid to metal ions ratio (R) on the structural and electrochemical properties of the synthesized compound was studied. Samples with high R (R ¼ 1; 2) contain large amount of MnO impurity phase, which is electrochemically inactive and thus is detrimental to the electrochemical activity of the electrode. Therefore, the acid to metal ions ratio ''R'' should not be high. Samples with low R (R ¼ 0:5) exhibited a high initial capacity, above 190 mAh/g when cycled at a current density of 0.4 mA/cm2 at room temperature. The ac impedance results show that the initial capacity was improved (compared with ss-o-$LiMnO_2$) due to the smaller particle size and good homogeneity, which improves the Liþ diffusion in the cathode.

***A New Synthetic Method for Preparing $LiFePO_4$ with Enhanced Electrochemical Performance.*** J. of New Materials for Electrochemical Systems 6, 259(2003)

**Z.P. Guo, H. Liu, S. Bewlay, H.K. Liu, and S.X. Dou**

The paper describes synthesis and properties of $LiFePO_4$ cathode material prepared by a novel modified solid-state reaction. The novel aspect of the synthesis is based on the addition of a growth inhibitor (citric acid) to the precursor. The citric acid addition does not affect the structure of the cathode but considerably improves its electrochemical performances because small particle size powders are obtained. A cell discharged at 17 mA/g was able to deliver a specific capacity of 167 mAh/g with good capacity retention. EIS experiments verified that the charge transfer has been improved compared to the sample prepared by the conventional solid-state reaction.

***Characterization of Layered $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$ Cathode Materials Prepared by Spray-Drying Method*,** J. of New Materials for Electrochemical Systems, 6, 263(2003)

**Z.P. Guo, H.Liu, H.K. Liu, S.X. Dou**

Layered structure $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$ was prepared by a spray drying method and characterized by means of x-ray diffraction and charge-discharge cycling. The hexagonal lattice parameters obtained for samples sintered at 800°C are a = 2.863Å and c = 14.244Å. The intensity ratio of the (003) to (104) peaks in the XRD pattern is 1.21. A discharge capacity of 154 mAh/g can be obtained in the range of 2.5-4.3 V at a specific current of 30 mA/g, and the rechargeable capacity for samples sintered at 800°C is more than 140 mAh/g. Compared to the $LiCoO_2$ electrode, the $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$ electrode has a comparatively high rate capability, so that $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$ is a promising candidate to replace $LiCoO_2$ cathode material for lithium-ion batteries.

***Structure and Electrochemical Characteristics of $LiMn_{0.7}M_{0.3}O_2$ (M=Ti, V, Zn, Mo, Co, Mg, Cr)***, Journal of Alloy & Compounds, 348, 231(2003)

**Z.P. Guo, S. Zhong, G.X. Wang, H.K. Liu, S.X. Dou**

A series of compounds $LiMn_{0.7}M_{0.3}O_2$ (M= Ti, V, Zn, Mg, Mo, Co, Cr) with different doping elements were synthesized. It was found that the ionic size of the doping elements is not a discriminating factor in the structure of $LiMn_{0.7}M_{0.3}O_2$ compounds. The $LiMn_{0.7}M_{0.3}O_2$ (M=Cr, Zn, Mg, V) forms in the hexagonal structure, while the $LiMn_{0.7}M_{0.3}O_2$ (M=Co, Ti, Mo) shows an orthorhombic structure. The $LiMn_{0.7}M_{0.3}O_2$ compounds have less crystal distortion compared with o(orthorhombic)-$LiMnO_2$. All substituted materials cycled between 4.4 and 2V in Li cells show higher stability of capacity compared with the standard o-$LiMnO_2$. AC impedance analysis results show that the charge transfer process and lithium ion diffusion process for doped $LiMnO_2$ compounds are better than that for un-substituted compounds.

***Magnetic shielding in $MgB_2$/Fe superconducting wires,*** IEEE Trans. Appl. Supercond. 13 (2003) 3324-3327.

**J. Horvat, S. Soltanian, X. L. Wang and S. X. Dou**

Magnesium diboride wires give the largest critical current when they are sheathed with iron. Iron sheath can shield the superconducting MgB_2 core from the external magnetic field. First MgB_2/Fe wires gave surprisingly high critical currents at elevated fields, which was ascribed to magnetic screening. Measurements of AC loss also showed that the loss is negligible up to 0.2T for the wires measured, due to effective shielding of the external field. However, measurements of the field dependence of critical current of MgB_2/Fe wires showed that critical current very weakly depends on the field for high fields, for which the magnetic screening of the superconducting core by the iron sheath is not effective. Without the iron sheath, a fairly strong field dependence of critical current was obtained. Therefore, there is a mechanism, beside the mere magnetic shielding, that strongly improves the overall field dependence of critical current in MgB_2/Fe wires. Dependence of this mechanism on the temperature and characteristics of the magnetic sheath is reported in this paper.

***Magnetic shielding in $MgB_2$/Fe J. Horvat, "Interaction of Superconductor with magnetic sheath as a way for improvement of critical current in $MgB_2$/Fe superconductor"***, in *Focus on Superconductivity*, Edited by B. P. Martins, Nova Science Publishers, 2004, pp.175-190.

**J. Horvat**

Magnesium diboride superconducting wires give the largest critical current density ($J_c$) when produced with iron sheath. Because iron is ferromagnetic, it is expected to improve the field dependence of $J_c$ by shielding of the external field for low magnetic fields. However, transport and magnetic measurements of $J_c$ reveal that $J_c$ in $MgB_2$/Fe is improved far beyond the effect of simple magnetic shielding. The transport measurements in external field show that $J_c$ initially decreases with the field. This is followed by an increase for intermediate fields and again a decrease for high fields, resembling the "peak effect". The value of $J_c$ in the field range of this peak effect is higher than the $J_c$ without iron sheath. The field range of improved $J_c$ widens with decreasing the temperature, shifting to the higher values of the field. The explanation of this phenomenon is suggested in terms of a model predicting the occurrence of overcritical state, as a result of interaction between partly vortex filled superconductor and a magnet. In this model, the currents are pushed into vortex-free volume of the superconductor, effectively increasing its value of loss-free current. The occurrence of the overcritical state is supported by magnetic measurements of $J_c$.

***Stoichiometry controlled high performance $LiCoO_2$ electrode materials prepared by a spray solution technique***, J. Power Sources **119-121** (2003) 195.

**K. Konstantinov, G. X. Wang, J. Yao, H. K. Liu and S. X. Dou**

$LiCoO_2$ cathode materials have been prepared by a spray drying technique. The stoichiometry of the materials, their morphology, and the phase composition and electrochemical performance have been studied. The effects of thermal annealing and decomposition processes on the structure are discussed in detail. The changes of Li content in materials were monitored by ICP spectrometry. It was established that the decomposition of the acetates at around 450$^o$C is a slurry–making process that compacts the powder. It was found that well lithiated samples with good cycle life and high capacity can be prepared using acetate precursors and a spray solution technique. The morphology, grain size and texturing can be controlled by the sintering time and temperature in combination with intermediate grinding.

***Spray pyrolysis technique for fabrication of nano-sized spherical agglomerated oxide powders for batteries***, J. Metastable and Nanocrystalline Mater. **15-16** (2003) 325.

**K. Konstantinov, J. Wang, S. Bewlay, G. X. Wang, H. K. Liu and S. X. Dou,**

Application of the spray pyrolysis technique to in-situ fabrication of nano-featured spherical oxide materials has been explored in this paper. Two different nano-featured single-phase materials for battery use, namely $LiCoO_2$ and PbO, were successfully prepared in spherical form. The diameters of the spheres are in the range of a few microns, generally 1-10 microns, and there is a narrow Gaussian particle size distribution. The diameter size can be controlled by the size of the spray nozzle and the concentration of the solution. The spherical agglomerates appear to consist of nano-particles, each one with dimensions of 20-50 nm. The specific surface areas of these materials are several times higher than for the corresponding commercially available powders. The stoichiometry of the $LiCoO_2$ powders thus obtained was controlled by the ICP technique in order to achieve the desired Li:Co = 1:1 ratio in the sintered materials. The materials prepared by the spray pyrolysis technique appear to be promising for battery use.

***In-situ production of nano-structured ceramics by spray solution technique***, Proc. Advanced Materials for Energy Conversion II, TMS Annual Conference 15-18 March 2004, Charlotte, USA, pages 331-338.

**K. Konstantinov, Z. W. Zhao, L. Yuan, H. K. Liu and S. X. Dou**

Various nano-structured $M_xO_y$ ceramics, e.g. CoO, $Co_3O_4$, $SnO_2$, and NiO, have been prepared in-situ by a spray pyrolysis method. The effects of the temperature and sintering time on nano-crystallinity, phase composition, and other physical or electrochemical parameters have been studied in detail. Different methods including X-ray diffraction, gas sorption analysis (for estimation of BET surface area), and TEM and SEM techniques, combined with EDX analysis and standard battery testing methods have been used to characterized the powders obtained. We have demonstrated that the method used is flexible and universal, and it permits good control of the crystal size and phase product, allowing in-situ production of simple or complex ceramics possessing specific surface areas that are generally larger than for the corresponding materials obtained via conventional technology. The obtained materials have promising potential applications as anode battery materials, catalysts or capacitors.

***Effects of magnetic field on vortex dynamics in (Tl, Pb)(Sr, Ba)$_2$Ca$_2$Cu$_3$O$_y$ single crystal,*** Physica C 399 (2003) 15-21

**S. Keshavarzi, M.J. Qin, X.L. Wang, H.K. Liu and S.X. Dou**

The flux dynamics of a (Tl, Pb)(Sr, Ba)$_2$Ca$_2$Cu$_3$O$_y$ single crystal have been investigated by means of magnetic relaxation measurements, with the applied field parralel to the c-axis. A power law dependece of the activation energy on the current densities for fields less than 2T over the temperature range 15-45 K has been observed, consistent with three dimansional large bundle vortes creep. For intermediate fields ( 2-3 T ) the flux dynamics are dominated by plastic vortex creep, while for fields higher than 3T over the temperature range 16-46 K, the vortex glass scaling aproach implied that a two-dimensional vortex structure is unlikely for fields less than 5T.

***Dip effect in ac susceptibility due to surface barrier with flux creep*,** Phys. Rev. B **68**, 214511 (2003)

**X. Leng, S. Y. Ding, Y. Liu, and Z. H. Wang, H. K. Liu and S. X. Dou**

A model is proposed to describe the effect of surface barrier (SB) on ac susceptibility (ACS) and a different kind of dip effect (DE) in ACS is observed. Simulation based on this model with flux creep reveals two dips in ACS curve, one at temperature *T*'d in real part x' and the other at temperature *T*"d in imaginary part x". These two dips are different from the ones resulting from the peak effect in critical current density *j*c, where the dips in x' and x" occur at the same temperature *T*p . The DE is also characterized by a large x" and a large x'(*T*'8). The ACS curves for single crystals Bi2Sr2CaCu2O8 have been observed and compared with the DE in YBa2Cu3O7 samples, confirming the numerical results. It is also shown that when flux creep is absent only kinks appear in x' and x" for a sample with SB.

*Effect of sintering temperature on microstructure and critical current density of nanocrystallined $MgB_2$ thick films prepared using very fast formation method,* J. Metastable and Nanocrystalline Materials, 15-16 (2003) 349

**A.H. Li, X.L. Wang, S. Soltanian, M. Ionescu, J. Horvat, H.K. Liu, and S.X. Dou**

The $MgB_2$ thick films on stainless steel have been prepared using a short time sintering method. The effect of the sintering temperature ranging from 745 to 840 $^oC$ on the phase formation, microstructure, and critical current densities have been investigated. XRD results show that single phase $MgB_2$ phase can be easily formed in the very short time (as little as minutes) for all the sintering temperatures. All the samples have almost the same phase purity and only contain less than 10% MgO. SEM results show that the grain sizes in the fast formed samples are nanometers and decrease as sintering temperature increases. The higher sintering temperature gives better grain connectivity than the lower temperatures. The Jc increased one order magnitude and irreversibility field determined from M-H loops also increases when sintering temperature increases from 745 to 840 $^oC$. The best $J_c$ of $0.7 \times 10^6$ A/cm$^2$ at 15 K has been achieved for films sintered at 840 $^oC$ for only 3 minutes.

***Intense vortex pinning enhanced by semi-crystalline defect traps in self-aligned nanostructured $MgB_2$*** *App. Phys. Lett.* 83, 2, 314-316 (2003)

**S. Li, T. White, K. Laursen, T.T. Tan, C.Q. Sun, Z.L. Dong, Y. Li, S.H. Zhou, J. Horvat and S.X. Dou**

In this work, we report the discovery of a vortex pinning source – semi-crystalline defect wells in self-aligned nanostructured $MgB_2$. It is demonstrated that these aperiodic regions trap numerous crystal defects migrating along nanodomain boundaries during self-alignment and act as intense vortex pinning centers that significantly enhance the high-field performance of $MgB_2$. This suggests that the density of trapped defects in the wells is much greater than found in other vortex pinning sources.

***Al-based anode materials for Li-ion batteries,*** J. Power Sources **119-121**, 84-87 (2003)

**M.J. Lindsay, G.X. Wang and H.K. Liu**

The electrochemical performance of Fe2Al5 was investigated as an anode material for lithium-ion batteries. Fe2Al5 was prepared by arc melting the constituent elements, crushing to a suitable size and then ball milling. By removing samples from the ball mill at various times the effect of milling time on the electrochemical properties was examined. The highest discharge capacity (485 mAh/g) observed was as a result of ball milling for 10,000 min which is consistent with the theoretical capacity for formation of AlLi (543 mAh/g). Cyclic voltammetry and differential capacity plots, however, do not offer conclusive evidence of the formation of AlLi. Both charge and discharge capacity improved with increasing milling but cycle life remained poor. Removal of lithium from the structure was difficult with charge capacities being quite low. The first charge capacities for instance were in the range of 20–40% of the first discharge capacity.

***A comparison of Ag and Ag-alloy sheathed Bi-2223 tapes,*** IEEE, Trans. On Appl. Supercond. **13,** 3004-3007 (2003)

**H.K. Liu, Z.M. Zhang, R. Zeng, J. Horvat and M. Apperley**

Ag and Ag-alloy sheathed Bi-2223 tapes were fabricated by a powder-in-tube technique with different configurations of the precursor and restack sheath materials: Ag, AgAu7wt%, AgSb0.6wt%, AgMg0.2wt%. Analysis of the $I_c$ and volume fractions of the Bi-2223, Bi-2212, Bi-2201 and Bi-3221 phases indicated that volume fractions of Bi-2223>90%, Bi-2212 ~ 5%, Bi-2201 ~ 0% and Bi-3221 < 2%, normally result in tapes with the highest $I_c$. The mechanical properties of the tapes revealed consistent results. Generally, the harder the sheath material, the higher tolerance to the bending strain and higher the tensile strength of the tape. The sequence of the alloys' hardness from highest to lowest was AgMg0.2wt%, AgSb0.6wt%, AgAu7wt% or Ag.

***Effect of nano-SiC and nano-Si doping on critical current density of $MgB_2$,*** Tsinghua Sci & Tech. **6, 11,** 307-315 (2003)

**H.K. Liu, S.H. Zhou, S. Soltanian, J. Horvat, A. Pan, M.J. Qin, X.L.Wang, M. Ionescu, and S.X. Dou**

The discovery of superconductivity in magnesium diboride ($MgB_2$) has opened up a new field in materials science research. It offers a possibility of a new class of high performance superconducting materials for practical applications because of the relative low cost of fabrication, high critical current densities ($J_c$) and fields, large coherence length, absence of weak links, higher $T_c$ ($T_c$ = 39 K) compared with $Nb_3Sn$ and Nb-Ti alloy (two or four times that of $Nb_3Sn$ and Nb-Ti alloy respectively). However, the weak flux pinning in magnetic field remains a major challenging. In this paper, we report the most interesting results on nanomaterials (SiC and Si) doping in magnesium diboride. The high density of defects at nano-scale introduced by doping is responsible for the enhanced pinning. We also discuss the fabrication method, critical current density, microstructures, the flux pinning and the cost for magnesium diboride bulks, wires and tapes. It is believed that the high performance SiC doped $MgB_2$ will have a great potential for many practical applications at 5K to 25K up to 5T.

***Thermal and optical determination of temperature on a multilayer thermionic device,*** Physica E17, 651 (2003)

**B. Lough, S. P. Lee, Z. Dou, R. A. Lewis, and C. Zhang**

We report our recent experimental investigation on the cooling power of GaAlAs-GaAs semiconductor multiplayer structures. Electrical and thermal conduction measurements were performed on multilayer structures to determine the temperature gradient across the sample. AuGe was used for top contact metallization, and an InGa eutectic for bottom substrate contact. The electron transport across the structure is nonisothermal. By using a variable load resistor connected in series with the device, we can accurately determine the current-voltage characteristics of the device. Thus the power input can be obtained. The temperature distribution on the top and bottom substrate were measured with micro thermocouples and by differential reflectance spectroscopy. Since the cooling device is grown on an n-type semiconductor substrate, there is significant joule heating in the substrate. The temperature increase under positive bias is due to the joule heating of the substrate and power generated in the multiplayer device. Under a reverse bias, part of the joule heating is cancelled by the cooling effect of the device.

***Effects of fission fragment damage on vortex dimensionality in silver-sheathed $Bi_2Sr_2Ca_2Cu_3O_x$ tapes***, Phys. Rev. B 68 (2003) 064518.

**D. G. Marinaro, J. Horvat, S. X. Dou, R. Weinstein and A. Gandini**

We report on the vortex dimensionality of uranium-doped Ag/Bi2223 tapes, before and after irradiation to a thermal-neutron fluence. The effective activation energies as a function of current density and applied field were calculated from dynamic magnetisation relaxation measurements. A dimensional crossover from a 3D elastic creep regime to 2D plastic creep was observed in the nonirradiated tape at an applied magnetic field $\mu_0 H_{cr} \approx 0.37$ T, with an associated change in the flux hop velocity and temperature dependence. After introduction of the fission-fragment damage by irradiation, a shift in the crossover to $\mu_0 H_{cr} \approx 0.65$ T was observed. These results indicate an enhancement of the *c*-axis vortex coherence by the introduced splayed columnar defects, explaining the greater pinning efficiency of the uranium-fission method in Bi2223 rather than the less anisotropic Y123. Conflicting results obtained for the irradiated tape in the absence of any temperature scaling of the activation energies demonstrate the importance of the inclusion of scaling in the magnetisation relaxation analysis.

***Magnetic flux distribution in the superconducting core of Bi-2223 tape,*** Physica C 388-389, pp. 405-406 (2003)

**A. V. Pan, S.X. Dou, and H.K. Liu**

Local magnetic flux distribution in the superconducting core of a Bi-2223 tape is investigated above and below a characteristic field B_, which is defined by global critical current density Jc measurements. Below this field, Jc as a function of applied magnetic field Ba exhibits a Ba-independent plateau often referred to the single vortex pinning regime. We show that below B_ the flux distribution within the core does not change. Furthermore, the strong $B^*(T)$ dependence is suggested to be due to thermally activated depinning of individual vortices.

***3D–2D-like vortex transition above $B_{c2}$ in niobium films***, Physica B 329–333 (2003) 1377–1378

**A. V. Pan, R. Hohne, and P. Esquinazi**

Isotropic superconducting Nb-films thicker than the penetration depth exhibit a magnetically anisotropic structure within the magnetic field range $B_{c2} \leq B_a \leq B_{c3}$; where $B_a$ is the applied field, and $B_{c2}$ and $B_{c3}$ are the upper and surface superconductivity critical fields, respectively. The anisotropic structure of the films consists of three layers: two superconducting surface layers and normal layer in between. Upon tilting the field with respect to the film surface, we have found that surface vortices undergo a 3D–2D-like dimensional crossover. Vortices residing on each of both film surfaces are coupled at fields almost parallel to the surface (3D), and decoupled at larger angles (2D) within the surface superconductivity state.

***Overcritical State in Fe-sheathed $MgB_2$ Superconducting Wires*****,** Proc. 27th Annual A&NZIP Condensed Matter and Materials Meeting, eds. J. Cashion, T. Finlayson, D. Paganin, A. Smith and G. Troup, AIP 2003. http://www.aip.org.au/wagga2003/Hubpage.pdf

**A. V. Pan, S. Zhou, H. Liu and S. Dou**

Magnetization measurements carried out on $MgB_2$ superconducting round wires have shown that the critical current density $J_c$ in wires sheathed by iron can be significantly higher than in the same unsheathed wires over a wide range of magnetic fields applied transversely to the cylindrical wire axis. Magnetic interactions between the magnetic sheath and the superconducting core are responsible for the enhancement. A phenomenological model is proposed to account for the observed overcritical behaviour.

***Direct visualization of iron sheath shielding effect in $MgB_2$ superconducting wires*** Supercond. Sci. Technol. **16**, pp. L33-L36 (2003)

**A. V. Pan, S. Zhou, H. Liu and S. Dou**

Local magneto-optical imaging and global magnetization measurement techniques were used in order to visualize shielding effects in the superconducting core of $MgB_2$ wires sheathed by ferromagnetic iron (Fe). The magnetic shielding can provide a Meissner-like state in the superconducting core in applied magnetic fields up to ~1 T. The maximum shielding fields are shown to correlate with the saturation fields of magnetization in Fe-sheaths. The shielding has been found to facilitate the appearance of an overcritical state, which is capable of achieving a critical current density (Jc) in the core which is larger than Jc in the same wire without the sheath by a factor of ~2. Other effects caused by the magnetic interaction between the sheath and the superconducting core are discussed.

***Properties of superconducting $MgB_2$ wires: ``in-situ'' versus ``ex-situ'' reaction technique***, Supercond. Sci. Technol. **16**, pp. 639-644 (2003)

**A. V. Pan, S. Zhou, H. Liu and S. Dou**

We have fabricated a series of iron-sheathed superconducting wires prepared by the powder-in-tube technique from $(MgB_2)_{1-x}$:$(Mg+2B)_x$ initial powder mixtures taken with different proportions, so that x varies from 0 to 1. It turned out that ``ex-situ'' prepared wire (x = 0) has considerable disadvantages compared to all the other wires in which ``in-situ'' assisted (0 < x < 1) or pure ``in-situ'' (x = 1) preparation was used due to weaker inter-grain connectivity. As a result, higher critical current densities Jc were measured over the entire range of applied magnetic fields Ba for all the samples with x > 0. Pinning of vortices in $MgB_2$ wires is shown to be due to grain boundaries. Jc(Ba) behavior is governed by an interplay between the transparency of grain boundaries and the amount of ``pinning'' grain boundaries. Differences between thermo-magnetic flux-jump instabilities in the samples and a possible threat to practical applications are also discussed.

***Mechanisms of Limitation and Nature of Field Dependencies of Critical Current in HTS Epitaxial YBaCuO Films*** ,IEEE Trans. Appl. Supercond. 13, pp. 3714-3717 (2003)

**V.M. Pan, E.A. Pashitskii, S.M. Ryabchenko, V.A. Komashko, A.M. Pan, S.X. Dou, A.L. Kasatkin, A.V. Semenov, C.G. Tretiatchenko and Y.V. Fedotoy**

Magnetic field and temperature dependencies of the critical current density, $J_c(H \parallel c, T)$ were measured by SQUID-magnetometry, ac magnetic susceptibility, and dc transport current techniques in the single-crystalline epitaxially-grown by off-axis dc magnetron sputtering $YBa_2Cu_3O_{7-\delta}$ (YBCO) films with $J_c(H \parallel c$, 77 K$) \geq 2\cdot10^6$ A/cm$^2$. Two competetive mechanisms of $J_c$-limitation are supposed: depairing/transparency mechanism and depinning mechanism. The mechanism of vortex depinning from growth-induced linear defects, i.e. out-of-plane edge dislocations in low-angle tilt domain boundaries, is shown to desribe quantitatively measured $J_c(H \parallel c, T)$. The developed model takes into account a statistic distribution of the dislocation domain boundaries ordered in a network as well as the interdislocation spacing within boundaries. Actual structural features of YBCO film known from HREM data turn out to be extracted from $J_c(H \parallel c, T)$-curves by fitting procedure within the proposed model.

***Transport critical current of Solenoidal $MgB_2$/Cu Coils Fabricated Using a Wind-Reaction In-situ Technique, Superconductor Science and Technology (Rapid Communication),*** 16 (2003) L4-L6.

**S. Soltanian, J. Horvat, X.L. Wang, M. Tomsic and S.X. Dou**

In this letter, we report the results on transport $J_c$ of solenoid coils of up to 100 turns fabricated with Cu-sheathed $MgB_2$ wires using a wind-reaction *in situ* technique. Despite the low density of the single core and some reaction between the Mg and Cu sheaths, our results demonstrate that the decrease in transport $J_c$ with increasing length of $MgB_2$ wires is insignificant. Solenoid coils with diameter as small as 10 mm can be readily fabricated using a wind-reaction *in situ* technique. The $J_c$ of the coils is essentially the same as that of comparable straight wires. A $J_c$ of 133 000 A/cm$^2$ and 125 000 A/cm$^2$ at 4 K and self-field has been achieved for a small coil wound using Cu-sheathed tape and Cu-sheathed wire, respectively. These results indicate that $MgB_2$ wires have a great potential for large-scale applications.

***Effect of nano-carbon particle doping on the flux pinning properties of $MgB_2$ superconductor***, Physica C 390 (2003) 185.

**S. Soltanian, J. Horvat, X. L. Wang, P. R. Munroe, S. X. Dou**

Polycrystalline $MgB_{2-x}C_x$ samples with x=0.05, 0.1, 0.2, 0.3, 0.4 nano-particle carbon powder were prepared using an in-situ reaction method under well controlled conditions to limit the extent of C substitution. The phases, lattice parameters, microstructures, superconductivity and flux pinning were characterized by XRD, TEM, and magnetic measurements. It was found that both the *a*-axis lattice parameter and the $T_c$ decreased monotonically with increasing doping level. For the sample doped with the highest nominal composition of x=0.4 the $T_c$ dropped only 2.7K. The nano-C-doped samples showed an improved field dependence of the $J_c$ compared with the undoped sample over a wide temperature range. The enhancement by C-doping is similar to that of Si-doping but not as strong as for nano-SiC doped MgB2. X-ray diffraction results indicate that C reacted with Mg to form nano-size $Mg_2C_3$ and $MgB_2C_2$ particles. Nano-particle inclusions and substitution, both observed by transmission electron microscopy, are proposed to be responsible for the enhancement of flux pinning in high fields.

***Effect of sample size on the magnetic critical current density in nano-SiC doped $MgB_2$ superconductor*****, Physical Review B, 68 (2003) 134509**.

**S. Soltanian, M. J. Qin, S. Keshavarzi, X. L. Wang, and S. X. Dou,**

The effect of sample size on the critical current density and the flux pinning of pure and SiC doped $MgB_2$ bulk samples has been investigated. At high fields a systematic degradation of magnetic $J_c$ and $H_{irr}$ was observed as the sample size decreased. However, $J_c$ remarkably increased on decreasing the sample volume at low magnetic fields below 1T. The SiC doped samples show less sample size effect than the pure samples, indicating a larger n-factor and therefore a stronger pinning effect due to SiC doping. $H_{irr}$ was observed to decrease as a logarithmic function of the sample volume, and the zero field $J_c$ can be fitted as an exponential decay function. A shift in the peak of the pinning force to lower magnetic fields was observed as the sample volume decreased.

***Effect of grain size and doping level of SiC on the superconductivity and critical current density in $MgB_2$ superconductor*, IEEE, Transaction on Applied Superconductivity, 13 (2003) 3273**.

**S. Soltanian, X. L. Wang, J. Horvat, M. J. Qin, H. K. Liu, P. R. Munroe, S. X. Dou**

SiC doped $MgB_2$ polycrystalline samples were fabricated by in-situ reaction using different grain sizes (20 nm, 100 nm, and 37 μm) of SiC and different doping levels (0, 8, 10, 12, 15 wt %). Phases, microstructures, superconductivity, critical current density and flux pinning have been systematically investigated using XRD, SEM, TEM, and magnetic measurements. Results show that grain sizes of the starting precursors of SiC have a strong effect on the critical current density and its field dependence. The smaller the SiC grains are, the better the $J_c$ field performance is. Significant enhancement of $J_c$ and the irreversibility field $H_{irr}$ were revealed for all the SiC doped $MgB_2$ with additions up to 15 wt%. A Jc as high as 20,000 A/cm$^2$ in 8 Tesla at 5 K was achieved for the sample doped with 10 wt% SiC with a grain size of 20 nm. Results indicate that the nano-inclusions and substitution inside $MgB_2$ are responsible for the enhancement of flux pinning.

*Zinc doping effects on the structure, transport and magnetic properties of La0.7Sr0.3Mn1-xZnxO3 manganite oxide,* Sci. & Tech. of Advanced Materials, vol.4, no.2, March 2003, pp.149-52. Publisher: Elsevier, UK

**E. Sotirova-Haralambeva, X.L. Wang, H.K. Liu, T. Silver, K. Konstantinov and J. Horvat**

The processing, microstructures and properties of La0.7Sr0.3M1-xZnxO3 erovskite manganite, with x=0, 0.1, 0.2, and 0.3 have been investigated. X-ray diffraction, scanning electron microscopy (SEM) and other characterisation methods were used to study the relations of microstructure and properties. The X-ray powder diffraction results show a single phase for the 0<x<0.3 region that confirms the zinc incorporation into the Mn site. The SEM images indicate that the studied system is a single phase. The transport measurements show decreasing of insulator to metal transition temperature, T/sub t/, with increasing the zinc concentration on the Mn site, while the resistivity increases with increasing the zinc doping level for 0<x<0.1. The maximum resistivities are found at 380 and 160 K, respectively. The PPMS measurements show that the magnetisation value is greatest for x=0.1 and drastically decrease for the parent material, as well as with increasing the zinc doping concentration above 20%, when the compound changes from ferromagnetic to paramagnetic. The paramagnetic to ferromagnetic transition temperature variations, Tc, agrees with the insulator to metal variations, T t, from the transport measurements for the parent and 10% doped material. For zinc doping levels above 20%, the behavior of the studied system changes from ferromagnetic to paramagnetic. (21 References).

***Magnetic relaxation and hysteresis in Bi2212 single crystals doped with Fe and Pb***, IEEE Trans. Appl. Supercond. 13 (2003) 3770-3773.

**K. K. Uprety, J. Horvat, X. L. Wang, G. D. Gu, M. Ionescu. H. K. Liu, S. X. Dou and E. H. Brandt**

Magnetic hysteresis and magnetic relaxation measurements have been performed to study vortex pinning behaviour for pure, Fe doped and heavily Pb doped Bi2212 single crystals. Unlike pure and Fe doped single crystals, heavily Pb doped single crystals showed strong vortex pinning behaviour. We interpret the strong pinning in heavily Pb doped single crystals as arising from the improved Josephson coupling in Bi2212 single crystal after heavy Pb doping. In heavily Pb dopes single Bi2212 crystals, $H_{dis}(T)$ was observed to increase with increasing T. Here, $H_{dis}(T)$ is the order-disorder field that separates weakly elastically disordered vortex lattice from a plastically disordered vortex solid. However, in pure and Fe doped single crystals, $H_{dis}(T)$ was observed to be temperature independent. We also observed a shift of $T_{CR}$, a crossover temperature separating the two pinning regimes, to a higher temperature with heavy Pb doping of Bi2212 single crystals. On the other hand, $T_{CR}$ did not shift with Fe doping of Bi2212 single crystals. It is argued that the temperature dependence of $H_{dis}(T)$ and $T_{CR}$ in heavily Pb doped single crystals was related to the enhanced c-axis conductivity caused by Pb situated between the $CuO_2$ layers and imposing a 3D characteristics on the vortex lattice.

***Preparation and Characterisation of Carbon Nanotubes for Energy Storage*** (J. Power Sources 119-121 (2003) 16 –23.)

**G.X. Wang, Jung-ho Ahn, Jane Yao, Matthew Lindsay, H.K. Liu and S.X. Dou**

Multiwall carbon nanotubes (MWNTs) were synthesised using Chemical Evaporation Deposition (CVD). The morphology and microstructure of MWNTs were observed via HRTEM. The multiwall carbon nanotubes are entangled to bundles with a diameter of several tenth nano meters. Electrochemical properties of MWNTs were examined via a variety of electrochemical testing techniques. The MWNTs electrode demonstrated a reversible lithium storage capacity of 340 mAh/g with good cyclability at moderate current density. The kinetic properties of lithium insertion in MWNTs electrodes were characterised via a.c. impedance measurements. It was found that the lithium diffusion coefficient $D_{Li}$ decreases with an increase of Li ion concentration in MWNTs electrodes.

***Physical and electrochemical properties of doped lithium iron phosphate electrodes,*** 1st International Conference on Polymer Batteries and Fuel Cells, Jeju Island, Korea, June 1-6, 2003

**G.X. Wang, S.L. Bewlay, K. Konstantinov, HK Liu, SX Dou and J-H Ahn**

Stoichiometric and non-stoichiometric Mg-doped lithium iron phosphates were synthesised via spray-pyrolysis, followed by sintering at high temperature for crystallization. The spray pyrolysis process allows the homogeneous mixing of the ingredient reactants at atomic level. The electronic conductivities of the Mg-doped lithium iron phosphates have been drastically improved by four orders of magnitude, comparing to the undoped $LiFePO_4$. The electrochemical properties of as-prepared lithium iron phosphates were systematically measured by cyclic voltammetry and constant current charge/discharge cycling tests.

***Energy Storage Materials for Lithium ion Batteries*****,** International Conference & Exhibition, Adaptive Materials for a Modern Society, Sydney, Australia, Oct. 1-3, 2003

**G.X. Wang, S. Bewlay, M. Lindsay, Z.P. Guo, Jane Yao, K. Konstantinov, HK Liu and SX Dou**

A brief review of our research in developing advanced lithium-ion battery technology is presented in this paper. We have investigated a series of novel cathode and anode materials for lithium-ion batteries with improved energy density and electrochemical performance. The cathode materials include doped $LiM_xMn_{2-x}O_4$ spinels, $LiM_xNi_{1-x}O_2$ and $LiM_xMn_{1-x}O_2$ compounds with layered structures. We have also developed numerous innovative anode lithium storage materials such as Sn-graphite composites, $Cu_6Sn_5$, NiSi, $Ni_3Sn_4$ and $FeSi_2$ intermetallic alloys. The physical, structural and electrochemical properties of these newly developed electrode materials have been systematically characterized via a variety of techniques. These new electrode materials have great potential for improving the energy density of advanced lithium-ion batteries.

**Multiple ions doped lithium nickel oxide as cathode materials for lithium-ion batteries,** J. Power Sources 119-121 (2003) 189-194)

**G.X. Wang, Steve Bewlay , Jane Yao, Y. Chen, Z. P. Guo, H.K. Liu and S.X. Dou**

Several multiple ions doped lithium nickel oxides with a formula of $LiMn_xCo_yNi_{1-x-y}O_2$ were synthesized via solid-state reaction at high temperature. These phase pure $LiMn_xCo_yNi_{1-x-y}O_2$ compounds have a layered hexagonal structure. The electrochemical properties of these $LiMn_xCo_yNi_{1-x-y}O_2$ compounds were systematically investigated. Typical $LiMn_xCo_yNi_{1-x-y}O_2$ cathodes can deliver a capacity in the range of 140-180 mAh/g with fairly stable cyclability. The kinetics of lithium insertion in these cathodes were characterized via a.c. impedance measurements. These newly developed $LiMn_xCo_yNi_{1-x-y}O_2$ compounds show some great promises as cathode materials for lithium-ion batteries in the future with low cost and less toxicity.

***$LiTi_2(PO_4)_3$ with NASICON-type Structure as Lithium Storage Materials***, J. Power Sources 124 (2003) 231 – 236 (Communication))

**G. X. Wang, D. H. Bradhurst, S. X. Dou and H. K. Liu**

$LiTi_2(PO_4)_3$ with NASICON-type structure was prepared by a two-step solid-state reaction. X-ray diffraction confirms $LiTi_2(PO_4)_3$ compound having a NASICON structure: rhombohedral (S.G.: R-3c). Electrochemical measurements have shown that lithium can be electrochemically inserted into $LiTi_2(PO_4)_3$ structure with a maximum intake of 5.2 moles of lithium per mole of $LiTi_2(PO_4)_3$ compound and $[PO_4]$ tetrahedra could participate in the redox reaction. This corresponds to a lithium storage capacity of 360 mAh/g. The kinetic parameters of Li insertion in $LiTi_2(PO_4)_3$ NASICON were determined by an a. c. impedance technique. The charge transfer resistance ($R_{CT}$) and exchange current density ($i_o$) were invariable regardless of the state of Li insertion, which is associated with the unique structure characteristics of the NASICON skeleton. However, the Li diffusion coefficient $D_{Li}$ was found to vary with the state of Li insertion. $D_{Li}$ is in the range $1.4\times 10^{-11}$ to $1.2\times 10^{-9}$ $m^2/s$, which is much higher than for other intercalation materials.

***Lead-coated glass fibre mesh grids for lead-acid batteries***, J. App. Electrochem. **33** 1057-1061(2003)

**J. Wang, Z.P. Guo, S. Zhong, H.K. Liu and S.X. Dou**

A lightweight lead-coated glass fiber mesh grid was tested for use in valve-regulated lead-acid (VRLA) battery. Plates made with these new girds show a higher material utilization over a wide range of discharge rates (i.e., 20 to 200 mA $g^{-1}$) and temperature (i.e., -15 to 25 $^oC$) compared with conventional gravity-caste plates. The test results also give evidence that the lead-coated glass fiber grid can replace the conventional gravity-cast grid without causing any deleterious effects so far as the cycle life is concerned.

***Enhanced performance of VRLA batteries with a novel spirally- wound electrode design***, J. Power Sources **113**, 241-244 (2003

**J. Wang, H.K. Liu, S.X. Dou, S. Zhong, Y. Zhu and C. Fu**

A spirally-wound electrode has been designed, constructed and applied to VRLA cells. Because of its unique construction comprised of high strength, light-weight lead composite grids, comparatively thin plates and sufficient internal compression, this new design provides significant advantages over the conventional prismatic type of VRLA batteries. The total weight of grids and top lead used in a battery can be reduced by 40% compared with conventional cast grids. There was no positive active-material softening and expanding happened after over 300 deep cycles, and substantial improvement in sustaining the cycleability has been achieved. This technique also provides a new, convenient process for manufacturing a spirally-wound VRLA battery in a simple and cost competitive way.

*Synthesis Nanocrystalline $\alpha$-PbO and $\beta$-PbO Lead Oxides for Lead-Acid Battery*

**J. Wang, S. Zhong, K. Konstantinov, J.H. Ahn, H.K. Liu, and S.X. Dou**

Nanocrystalline $\alpha$-PbO and $\beta$-PbO lead oxides were prepared by using simple chemical reaction methods. The average crystallite size of synthesized lead oxides is less than 30nm, while the average crystallite size of conventional ball milled battery grade oxide is around 220nm. The synthesized nanocristalline lead oxide was tested as an active material for positive plate of lead- acid batteries. A commercial lead oxide was tested to compare with the synthesized nanocrystallite lead oxide. Plates made with these pure lead oxides can be formatted successfully through the case formation without requiring the conventional curing process. Test results show that the use of the pure nanocrystalline lead oxide not only eliminates the time-consuming curing process but also increases the positive electrode material utilization by.

***Beneficial effects of red lead on non-cured plates for lead-acid batteries***, J. Power Sources **113**, 371-375 (2003

**J. Wang, S. Zhong, H.K. Liu and S.X. Dou**

In order to find a convenient processing method and more suitable paste formula for making a VRLA battery, hydrogen peroxide solution and red lead ($Pb_3O_4$) has been used together during the paste preparation. The use of hydrogen peroxide solution to replace the conventional sulphuric acid solution can accelerate the oxidation of free lead in the paste and therefore reduce the time for plate curing, where the addition of red lead to the plates can enhance the cell formation efficiency and may also affect the cell performance. Based on these two beneficial functions, a new process for making VRLA cell was proposed and investigated. With the new processing, cells were assembled directly with freshly pasted plates without undergoing the conventional plate cuing/drying, and then the battery formation was followed successfully. The new processing shown an increase in the production efficiency and a reduction of production time and cost substantially. The battery performance, in term of the initial discharge capacity and cycle life is also enhanced by use conductive red lead.

***A novel cureless paste for positive plates in valve-regulated batteries***, J. Power Sources **122** 195-200 (2003)

**J. Wang, S. Zhong, X.L. Wang, H.K. Liu and S.X. Dou**

A new plate manufacturing technique for VRLA lead-acid battery has been developed. This involves the use of a novel paste preparation method, which employs hydrogen peroxide to replace the currently used sulfuric acid. The plates can be assembled directly into a battery case after pasting, and then a case formation can be performed directly without the plates undergoing the conventional curing process. The non-curing process could reduce the production time and cost significantly, and more importantly, the non-cured plates provide good flexibility which is particularly suitable for non-flat plate types of battery construction, such as the spirally wound battery configuration.

*Effect of nano-Y-$ZrO_2$ and $SiO_2$ addition on the microstructure and critical current density of $MgB_2$ superconductors* J. Metastable and Nanocrystalline Materials, 15-16 (2003) 721

**X.L. Wang, P.R. Munroe, P. Yao M. Ionescu, H.K. Liu, and S.X. Dou**

Polycrystalline $MgB_2$ samples with 10 wt % nano-Y-$ZrO_2$ (YSZ) or $SiO_2$ powder addition were prepared by an in-situ reaction process. The phases, microstructures, and flux pinning were characterized by TEM and magnetic measurements. TEM and EDS analysis indicated that both nano-YSZ and $SiO_2$ particles included in $MgB_2$ grains. Furthermore, the transition temperatures of both nano-particle doped sample are the same as for undoped samples. However, it was observed that the samples doped with YSZ powders showed a higher critical current density over a wide temperature range compared with undoped samples, whereas the nano-$SiO_2$ doped samples have a very poor flux pinning. It is proposed that the better Jc values in nano-YSZ doped samples were caused by nano-YSZ inclusions and the very weak-pinning in nano-$SiO_2$ added samples is due to weak-links caused by large amount of impurities that formed as a result of reaction between $SiO_2$ and $MgB_2$.

*Significant enhancement of flux pinning in MgB/sub 2/superconductor through nano-Si addition,* Physica C, vol.385, no.4, 1 April 2003, pp.461-5. Publisher: Elsevier, Netherlands

**X.L. Wang, S.H. Zhou, M.J. Qin, P.R. Munroe, S. Soltanian, H.K. Liu, S.X. Dou**

Polycrystalline MgB2 samples with 10 wt.% silicon powder addition were prepared by an in situ reaction process. Two different Si powders, one with coarse (44 mu m) and the other with nano-size (<100 nm) particles were used for making samples. The phases, microstructures, and flux pinning were characterized by XRD, TEM, and magnetic measurements. It was observed that the samples doped with nano-sized Si powder showed a significantly improved field dependence of the critical current over a wide temperature range compared with both undoped samples and samples with coarse-Si added. J/sub c/ is as high as 3000 A/cm2 in 8 T at 5 K, one order of magnitude higher than for the undoped MgB2. X-ray diffraction results indicated that Si had reacted with Mg to form Mg2Si. Nano-particle inclusions and substitution, both observed by transmission electron microscopy, are proposed to be responsible for the enhancement of flux pinning in high fields. However, the samples made with the coarse-Si powders had a poorer pinning than the undoped MgB2. (11 References).

***Electrochemical Studies of MCMB Carbon as an Anode in Lithium–ion Cells*****,** J. Power Sources 114 (2003) 292 – 297, communication

**J. Yao, G.X. Wang, J.-H, Ahn, H.K. Liu and S.X. Dou**

The electrochemical performance of MCMB carbon anodes in lithium-ion cells has been systematically studied via a variety of electrochemical techniques. MCMB carbon anodes have a stable lithium intercalation capacity of 325 mAh/g upon high rate charge/discharge cycling. Cyclic voltammetry shows only one reduction peak and one oxidation peak, corresponding to lithium-ion intercalation and de-intercalation respectively. The diffusion of lithium ions in the MCMB electrodes was characterized by a.c. impedance measurement.

***Nanosized Tin Microencapsulated Graphite as Anode in Lithium-ion cells***, Journal of Metastable and Nanocrystalline Materials 15-16 (2003) 739-744.)

**J. Yao, G.X. Wang, J.H. Ahn, H.K. Liu and S.X. Dou**

A series of new anode composite material for lithium-ion batteries was developed by microencapsulating nanosized Sn particles in graphite. The nanosized Sn particles are homogeneously dispersed in graphite matrix via in situ chemical reduction. The tin-graphite composite showed a great improvement in lithium storage capacity. Since Sn is an active element to lithium, Sn can react with lithium to form $Li_{4.4}Sn$ alloys, accompanying 400 % volume increase. Whereas the ductile graphite matrix provides a perfect buffer layer to absorb such volume expansion. Therefore, the integrity of the composite electrode is preserved during lithium insertion and extraction. The reaction process of lithium insertion and extraction in graphite structure and lithium alloying with tin has been identified by cyclic voltammetry measurement. The new tin-graphite composites provide a new type of anode materials for lithium-ion batteries with the increased capacity.

***Dynamical conductivity of a two-dimensional electron gas under an intense terahertz radiation, Physica E17, 289 (2003)***

**C. Zhang and B. Lough**

By using a kinetic description method, we calculate the conductivity of a two dimensional electron gas under an intense terahertz radiation. Our result includes all contributions from electron-photon side-bands and in lowest order of electron impurity scattering. Resonant absorption of electromagnetic waves by the coupled electron-photon system is discussed.

*In situ annealing of superconducting MgB2 films prepared by pulsed laser deposition,* Supercond. Sci. Technol. 16, 1487 (2003).

**Y. Zhao, M. Ionescu, A.V. Pan, S.X. Dou, E.W. Collings**

The *in situ* annealing conditions of pulsed laser deposited $MgB_2$ films were studied. The precursor films were deposited at 250□ from a stoichiometric $MgB_2$ target in a 120mTorr Ar atmosphere. The films were then *in situ* annealed at a temperature from 450□ to 800□ and an annealing time from 1 minute to 10 minutes. We found that the superconducting properties depend in a crucial way on the annealing conditions: temperature, heating rate and time. The best film with a thickness of ~600nm was obtained under the following annealing conditions: $T_{anneal}$=680-690□, $t_{anneal}$=1 min, heating rate= 38□/min. The $T_{c\ onset}$ of the film is 28K with a transition width of ~10K. The hysteresis loop of magnetic moment of the film indicates weak field dependence in high fields. Magneto-optical imaging of the film showed quite homogeneous magnetic flux penetration, indicating structural homogeneity. The films without annealing showed no superconductivity.

# Funded ARC Projects in 2004 round at ISEM

## ARC Centre of Excellence

***Nano-materials for energy storage***

| | | | | | |
|---|---|---|---|---|---|
| **Years funded:** | 2003 | 2004 | 2005 | 2006 | 2007 |
| **Amount funded:** | $198,174 | $198,174 | $198,174 | $198,174 | $198,174 |
| **Chief Investigator:** | H.K.Liu | | | | |
| **Research Fellow:** | G.X. Wang | | | | |
| **Postgrad Students:** | S.H. Ng, L.Q. Mai | | | | |

## ARC Large/Discovery Grants Scheme

***Enhancement of transport critical current density in magnetic fields of Ag/BiPbSrCaCuO tapes by fission tracks***

| | | | |
|---|---|---|---|
| **Years funded:** | 2001 | 2002 | 2003 |
| **Amount funded:** | $71,945 | $77,589 | $77,888 |
| **Chief Investigator:** | S.X. Dou | | |
| **Research Fellow:** | T. Silver | | |
| **Postgrad Students:** | D. Marinaro, D. Milliken | | |

An important application of high temperature superconductors (HTS) is in the area of high current and high magnetic field where a high critical current density, $J_c$, in strong magnetic fields is essential. It is well accepted that $J_c$ of Ag/BiPbSrCaCuO tapes is limited by the grain connectivity in the self-field, but by flux pinning in an applied field. The objective of this project is to enhance flux pinning by using a combination of stable uranium compound doping and thermal neutron irradiation to produce fission fragments to act as pinning centres. The expected outcomes will be improved Jc in magnetic fields and minimised anisotropy of HTS with radioactivity to a level acceptable for handling.

***Growth, characterisation and flux pinning behaviour of doped $TiSr_2Ca_2Cu_3O_y$ and $TiSr_2CaCu_2O_y$ and high temperature superconducting single crystals***

| | | | |
|---|---|---|---|
| **Years funded:** | 2001 | 2002 | 2003 |
| **Amount funded:** | $59,954 | $58,191 | $58,416 |
| **Chief Investigator:** | H.K. Liu | | |
| **Assoc.Investigator:** | M. Ionescu, X.L. Wang | | |
| **Researcher:** | Z.X. Cheng | | |

$TISr_2Ca_2Cu_3O_y$ (TISr-1223) and $TISr_2CaCu_2O_y$ (TISr-1212) exhibit significant improvement in critical current at high magnetic fields over the TI- and Bi-based high temperature superconductors (HTS). Flux pinning for both compounds has not been well investigated because of the extreme difficulties involved in growing single crystals. The aim of the proposed research is to investigate the growth, characterisation and flux pinning behaviour in Pb or Ba doped and undoped TISr-1212 and 1223 single crystals. This study will lead to a better understanding of the intrinsic flux pinning properties of both phases and be beneficial for application involving TI-or Bi-based HTS films and tapes.

***First Principles for Development of High Temperature Superconducting Wires***

| | | | | | |
|---|---|---|---|---|---|
| **Years Funded:** | 2002 | 2003 | 2004 | 2005 | 2006 |
| | $222,295 | $233,899 | $217,899 | $203,899 | $209,899 |
| **Total Funding:** | $1,087.891 | | | | |
| **Project ID:** | DP0211240 | | | | |
| **Chief Investigator:** | SX Dou, J Horvat | | | | |
| **Assoc. Investigator:** | H Weber, E Collings, J Habermeier | | | | |
| **Postgrad Student:** | S. Keshavarzi, M. Roussel | | | | |

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 focussing on the complex interplay between physics, fabrication and materials issues. The knowledge gained will make possible improvements in the development of HTS conductors.

***Enhancement and elucidation of flux pinning in doped Bi-Sr-Ca-Cu-O high temperature superconducting single crystals***

| | | | |
|---|---|---|---|
| **Funded:** | 2002 | 2003 | 2004 |
| **Amount Funded:** | $61,184 | $62,967 | $62,967 |
| **Total Funding:** | **$187,118** | | |
| **Project ID:** | DP0211328 | | |
| **Chief Investigator:** | X.L. Wang | | |
| **APD:** | X.L. Wang | | |

The proposed project aims to study the effects of elevated doping on the intrinsic electromagnetic properties of Bi-Sr-Ca-Cu-O high temperature superconducting (HTS) single crystals grown by two-dimensional and spiral-growth mechanisms with a particular focus on structure, conductivity and thermal neutron irradiation. Studies of the relationship between microstructures, anisotropy and flux pinning will lead to a better understanding of the pinning behaviour of Bi-based HTSC. The outcome will be better methods for introducing suitable pinning centres into Bi-based high temperature superconductors.

***Analysis, simulation, fabrication and characterization of reliable, robust and scalable compact cooling elements based on semiconductor nanostructures***

| | | | |
|---|---|---|---|
| **Funded:** | 2003 | 2004 | 2005 |
| **Amount Funded:** | $75,000 | $80,000 | $40,000 |
| **Total Funding:** | **$195,000** | | |
| **Project ID:** | DP0343516 | | |
| **Chief Investigator:** | C. Zhang, R.A. Lewis | | |
| **Postgraduate students:** | B.C. Lough, Z. Dou, S.P. Lee | | |

Project Summary: Modern electronic, microelectronic and optoelectronic devices generally work better when they are cooler. We aim to develop a semiconductor nanostructure cooling element which directly integrates into existing devices. The solid-state cooling element will be reliable, robust, scalable and operate in any orientation. The basis of operation is thermionic emission - electrons are the working fluid.

Our project combines (1) analysis and simulation, (2) fabrication of nanostructures and (3) experimental test-benching using optical and electrical methods. The outcome of this research has the potential to revolutionize cooling of modern electronic and photonic systems, from computer motherboards to mobile phones.

***Fabrication, Charge and Spin Ordering, Magnetoresistance, and polaron effects in nano-size and single crystals of novel transition metal perovskite oxide***

| | | | |
|---|---|---|---|
| **Funded:** | 2003 | 2004 | 2005 |
| **Amount Funded:** | $90,000 | $77,000 | $78,000 |
| **Total Funding:** | **$245,000** | | |
| **Project ID:** | DP0345012 | | |
| **Chief Investigator:** | X.L. Wang, M. Ionescu, Z.X. Cheng | | |
| **Partner Investigator:** | Dr.M James, Prof. R.S. Liu, Prof. W. Lang | | |
| **Postgraduate students:** | M. Farhoudi, G. Peleckis | | |

The aim of the project is to synthesize a systematic series of novel colossal magnetoresistance manganese, cobalt and iron based transition metal perovskite oxides in the forms of nano-structures, nano-structured composites and single crystals using advanced nano-technology and crystal growth techniques. Extensive fundamental studies on magnetoresistance, spin and change ordering, and nano-scale behaviours will be carried out by neutron diffraction, synchrotron radiation, transport and magnetic measurements over a wide temperature range and magnetic fields. The outcomes of this project are likely to lead to a better understanding of the colossal magnetoresistance mechanisms, the discovery of fascinating new physical phenomena and suitable magnetoresistance materials for superior magnetic recording, sensing and switch devices.

***Analysis, simulation, fabrication and characterization of reliable, robust and scalable compact cooling elements based on semiconductor nanostructures***

| | | | |
|---|---|---|---|
| **Funded:** | 2003 | 2004 | 2005 |
| **Amount Funded:** | $75,000 | $80,000 | $40,000 |
| **Total Funding:** | **$195,000** | | |
| **Project ID:** | | | |
| **Chief Investigator:** | C. Zhang, R.A. Lewis | | |

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

| | | | |
|---|---|---|---|
| **Funded:** | 2004 | 2005 | 2006 |
| **Amount Funded:** | $100,000 | $100,000 | $105,000 |
| Total Funding: | **$305,000** | | |
| **Project ID:** | DP0449629 | | |
| **Chief Investigator:** | S.X. Dou, M.J. Qin, | | |
| **Partner Investigator:** | D.C. Larbalestier, R.L. Flukiger, L.F. Cohen | | |
| **Postgraduate students:** | W.K. Yeoh, O. Scherbakova, Y. Zhang | | |

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. Zuettel, P.H. Notten | | |
| **APD**: | Mrs ZP 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. 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.

# ARC Research Fellowships

***Optimisation of thermal and mechanical processing and critical current density of Ag/(BiPb)-2223 Tapes***

| | | | | | |
|---|---|---|---|---|---|
| **Years funded:** | 1999 | 2000 | 2001 | 2002 | 2003 |
| **Amount funded:** | $95,278 | $90,666 | $92,238 | $94,230 | $113,000 |
| **Chief Investigator:** | H.K. Liu, Australian Professorial Fellow | | | | |

This proposal studies mechanisms of novel processing techniques that either together or separately are expected to enhance the critical current density of Ag-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ (Bi:2223). These include a cryogenic process for mechanical deformation, a two-step sintering for heat treatment, a quench, followed by a rapid heating used in between thermal cycles, the Bi:2223 formation-partial-decompositon process and partial decomposition under hot deformation. All these processes center about the kinetics and thermodynamics of phase transformation during each stage of processing. A combination of these innovative processes will result in an optimised process that leads to the best microstructure, substantially reduced processing time and a high $J_c$ in B:2223 tapes, making them suitable for applications.

# Strategic Partnerships with Industry - (SPIRT) Scheme - Linkage Projects & Linkage APAI

***Solid-state rechargeable lithium batteries for telecommunication and portable electronic devices***

| | | | |
|---|---|---|---|
| **Years funded:** | 2001 | 2002 | 2003 |
| **Amount funded:** | $60,234 | $74,080 | $63,922 |
| **Chief Investigator:** | GX Wang, H.K. Liu, S. Zhong | | |
| **Partner Investigator:** | X.Q. Yang | | |
| **Assoc. Investigator:** | D.H. Bradhurst | | |
| **Industry Partners:** | Australian Battery Technology, Lexel Battery Ltd. | | |

It is aimed to develop solid state rechargeable lithium polymer batteries and thin film microbatteries for telecommunications and miniature electronic devices. The significance of this project is to develop advanced solid-state rechargeable technology and stimulate advanced battery manufacture in Australia. The expected outcome will be to produce prototype lithium polymer batteries for cellular phones, notebook computers and palm computers. Thin-film microbatteries will also be fabricated using a pulsed laser ablation technique.

***Experimental development of thermionic cooling for domestic refrigeration***

| | | | |
|---|---|---|---|
| **Years funded:** | 2001 | 2002 | 2003 |
| **Amount funded:** | $22,292 | $22,292 | $22,292 |
| **Chief Investigator:** | R.A. Lewis, C. Zhang | | |
| **Industry Partner:** | Email Limited | | |
| **Postrad Student:** | Z. Dou | | |

The aim is to prove in practice the concept of solid-state cooling by thermionic emission for domestic refrigeration. The proposed experimental work follows naturally from the recent theoretical advances made in this area by us and others. A structure consisting of very thin, alternating layers of semiconductors is calculated to have high cooling efficiency. In contrast to standard compressor-based refrigerators, a refrigerator based on the new concept has no moving parts, is silent, vibration free, environmental friendly and low maintenance. The project links experts in semiconductor physics theory and experiment with Australia's largest manufacturer of domestic refrigerators, whose factory is regionally based (Orange, NSW).

***Developing New Cathode Materials for Lithium-ion Batteries Using Australian Mineral Resources***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $83,000 | $84,000 | $84,000 |
| **Total funding:** | $251,000 | | |
| **Project ID:** | LP0214179 | | |
| **Chief Investigator:** | Prof Shi Xue Dou, Dr G Wang | | |
| **Partner Investigators:** | Prof J Lee | | |
| **Research Fellow:** | K. Konstantinov | | |
| **APA(I) Award(s):** | S. Bewlay | | |
| **Industry Partner(s):** | Sons of Gwalia Ltd. OM Group | | |
| **Postgraduate students:** | Y. Chen | | |

This project will bring together expertise in electrochmistry, materials science and structure characterisation to conduct collaborative research with Australian industry partners, Queensland Nickel Technology Pty Ltd and Sons of Gwalia Ltd. The aims of this project will be to investigate a series of cathode materials for use in lithium-ion batteries. The significance of this research is that the technology for preparing a series of new electrode materials for lithium-ion batteries will be developed by taking advantage of abundant Australian minerals resourecs. The expected outcomes will be to identify several new cathode materials with high energy density, long cycle life, low toxity and low cost.

***Fabrication and Characterisation of Magnesium Diboride Superconducting Wires***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $110,000 | $100,000 | $100,000 |
| **Total funding:** | $310,000 | | |
| **Project ID:** | LP0219629 | | |
| **Chief Investigator:** | Prof Shi Xue Dou, Dr XL Wang, Dr M Ionescu | | |
| **Partner Investigators:** | Dr MD Sumption | | |
| **APA(I) Award(s):** | Yue Zhao, S. Soltanian | | |
| **Industry Partner(s):** | Alphatech International, | The Hyper Tech Research Inc. | |

The newly discovered superconductivity at 40K in magnesium diboride ($_{MgB2}$) opens a technical window to a range of electric power applications, previously thought accessible only with high temperature superconductors. The aim of the proposed project is to investigate the fabricability and properties of $_{MgB2}$ superconducting wires using a number of processing techniques established in previous low temperature and high temperature superconductors. The expected outcome is to have a $_{MgB2}$ conductor that has a higher performance in a field than niobium-titanium (NbTi) alloy, a higher operating temperature (up to 20K), but at a cost less than currently commercial NbTi wire.

***Investigation of Nano-materials for use in Lithium Rechargeable Batteries***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $67,000 | $60,000 | $60,000 |
| **Total funding:** | **$187,000** | | |
| **Project ID:** | LP0219309 | | |
| **Chief Investigator:** | Prof Hua Kun Liu, Dr S Zhong | | |
| **Partner Investigators:** | A/Prof J Ahn | | |
| **APA(I) Award(s):** | L. Yuan | | |
| **Industry Partner(s):** | Sons of Gwalia Ltd, | OM Group, | Lexel Battery Ltd |
| **Postgraduate student:** | Z.W. Zhao, M. Lindsay | | |

Lithium ion batteries are emerging as a new generation of rechargeable batteries for power sources of portable electronics. The aim of this project is to explore potential applications of novel nano-materials such as intermetallic alloys, transition-metal oxides, and carbon nanotubes as anode materials in lithium-ion rechargeable batteries. Significance and expected outcomes will be the development of alternative anode materials with improved performance in energy capacity and cycle life over existing anode materials. This could open opportunities for Australian mineral companies to take advantage of the developments to produce value-added new products.

***Fabrication of Magnesium Diboride ($MgB_2$) thick films***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $22,545 | $22,545 | $22,545 |
| **Total funding:** | **$67,635** | | |
| **Project ID:** | LP0228370 | | |
| **Chief Investigator:** | Dr X L Wang | | |
| **APA(I) Award(s):** | Q.W. Yao | | |
| **Industry Partner(s):** | SFC Enterprises Pty Ltd | | |

The recent discovery of superconductivity at 39 K in $_{MgB2}$ has stimulated considerable interest in terms of both fundamental research and applications. The purpose of the proposed project is to conduct fundamental studies on the synthesis, structures and microstructures, and physical properties of doped and undoped $_{MgB2}$ thick films. The ultimate goal of this study is to fabricate high quality $_{MgB2}$ thick films on different substrates and to gain a better understanding of their various properties with a view to device application.

***Lithium/Sulfur 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. Wang, G. Wang | | |
| **APD Award(s):** | J. Wang | | |
| **Industry Partner(s):** | Guangzhuo 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.

***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 | | |
| **Chief Investigator:** | G. Wang, H.K Liu, K. Konstantinov, J. Ahn, B. Ammundsen | | |
| **APA(I) Award(s):** | J. Yao | | |
| **Industry Partner(s):** | Pacific Lithium New Zealand Limited, Sopo Battery Energy Co., Ltd | | |
| **Postgraduate student:** | S. 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.

***Enhancing the Understanding and Performance of Passivating TiO2 Coatings for Photovoltaic Devices***

| | | | | |
|---|---|---|---|---|
| **Years funded:** | 2004 | 2005 | 2006 | 2007 |
| **Amount funded:** | $75,000 | $127,500 | $105,000 | $52,500 |
| **Total funding:** | **$360,000** | | | |
| **Project ID:** | LP0455328 | | | |
| **Chief Investigator:** | BS Richards, M Ionescu | | | |
| **Partner Investigators:** | KR McIntosh, KM Provancha, R Swanson | | | |
| **APA(I) Award(s):** | 1 | | | |
| **APDI** : | BS Richards | | | |
| **Industry Partner(s):** | Kieth McIntosh Consulting,<br>SierraTherm Production Furnaces, Inc.<br>SunPower Corporation | | | |

Titanium dioxide (TiO2) has been widely used as an antireflection coating in the silicon (Si) photovoltaics industry as it exhibits excellent optical properties and low deposition cost. However, recently manufacturers have been turning to alternatives such as hydrogenated silicon nitride coatings that exhibit greatly improved electronic properties, but cost 4 - 10 times more to deposit.

This project seeks to understand the fundamental limitations behind the poor surface passivation afforded by TiO2 to a Si wafer, and subsequently develop a passivating TiO2 coating that can reduce the cost of electricity generated by Si solar cells.

# ARC linkage-infrastructure

***T-ray factory: a new Australian source of strong, pulsed, broadband, terahertz radiation***

| | |
|---|---|
| **Years funded:** | 2004 |
| **Amount funded:** | $113,190 |
| **Project ID:** | LE0453974 |
| **Chief Investigator:** | R.A. Lewis, C. Zhang, H.H. Tan, A.M. Sanagavarapu, A.R. Hamilton |
| **Partner Institution(s):** | University of Wollongong<br>The Australian National University<br>University of Technology, Sydney<br>The University of New South Wales |

Australian scientists and engineers require immediate access to frontier T-ray (terahertz radiation) technology to solve pressing current problems in semiconductor nanostructures and emerging problems in fields as diverse as biophysics and national security. Recent innovations now make practical the production of bursts of terahertz radiation by applying ultrafast optical pulses to photoconductive or electro-optic media, facilitating unparalleled time-resolved spectroscopy and imaging. The state-of-the-art equipment to be purchased and installed at Wollongong will enhance the existing excellent terahertz infrastructure (unique spectrometers, optically-pumped molecular laser) and efficiently service researchers in the dynamic Sydney (UTS, UNSW) - Wollongong (UoW) - Canberra (ANU) corridor

# Linkage International Awards

***Development of Solid-state cooling chips***

| | | |
|---|---|---|
| **Years funded:** | 2002 | 2003 |
| **Amount funded:** | $11,700 | 9,500 |
| **Total funding:** | $21,200 | |
| **Project ID:** | LX0240472 | |
| **Chief Investigator:** | A/Prof RA Lewis, Dr C Zhang - University of Wollongong<br>Prof Q Huang - Institute of Physics, CAS | |

The objectives of this project were to develop thermionic cooling chips using semiconductor multiple quantum wells and superlattices. Under this grant, we carried out following collaborative activities.

1. In February 2002, the Australian CI, R A Lewis, visited the Institute of Physics, Chinese Academy of Sciences. The second generation sample structures and parameters were discussed and finalized.
2. Our MSc student, Sueping Lee visited the Institute of Physics for three months for the period of August—October 2002. During her visit, several devices with different sizes and different metallic contacts were fabricated using the molecular-beam-epitaxy (MBE) facilities in the Institute of Physics. This visit gave our student the opportunity to learn the layer-by-layer growth techniques using the MBE machine. The nanodevices we grew in Beijing were brought back to our group. Electrical and optical characterizations were performed on these samples.
3. In October 2003, the student from the Chinese Academy, X Shang came to Australia for a three month visit. He joined our measurement team to perform the electrical, thermal and optical measurements on the second generation samples. He also worked closely with our students on the device simulation. Due to small temperature differences detected in the second generation devices, we performed further simulations to choose the parameters required for optimal performance. The third generation devices were designed and will be fabricated by our OI in Beijing.
4. In December 2003, the Australian CI, C Zhang, visited the Institute of Physics for a week to discuss the progress and steps required for the next generation device fabrication.
5. In January 2004, a member of OI's group, Dr K Jin visited our group for two weeks to participate in our simulation work on the third generation devices

***Investigation of a series of metallic substrate materials suitable for developing long Y-Ba-Cu-O superconductors***

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $19,396 | $17,596 | $17,596 |
| **Total funding:** | $54,588 | | |
| **Project ID:** | LX0211084 | | |
| **Chief Investigator:** | Prof Hua Kun Liu - University of Wollongong | | |
| | Prof D Shi - University of Cincinnati | | |
| **Postgraduate students:** | A.H. Li | | |

Researchers from Institute for Superconducting and Electronic Materials, the University of Wollongong (UoW) & the Dept. Mat. Sci & Eng., University of Cincinnati (UC) in USA will build strong collaborations through joint research on a series of metallic substrate materials. Significance: The research work will contribute to the development of the second generation of high temperature superconducting wire technology. Expected outcomes: strengthen international research experience for junior researchers and develop new collaborations between senior researchers from UoW in Australia and UC in USA.

***Simulation and characterisation of opto-thermionic cooling devices***

| | | | |
|---|---|---|---|
| **Years funded:** | 2003 | 2004 | 2005 |
| **Amount funded:** | $15,700 | $18,700 | $18,700 |
| **Total funding:** | $53,100 | | |
| **Project ID:** | LX0348004 | | |
| **Chief Investigator:** | A/Professor C. Zhang, A/Professor R.A. Lewis | | |
| | CI Prof KA Chao Lund University, Sweden | | |

The aim of the project is to study and develop a solid state cooling device by combining two mechanisms, thermionic emission and optical recombination. The first stage of the research is to develop theoretical models and numerical methods which will allow us to obtain an optimal condition of power and efficiency. Under this ARC LX grant, mutual visits for the Australian CIs and the international OI have been arranged.

In August 2003, the international OI, K A Chao visited our group in Wollongong. During his visit, we discussed the theoretical and numerical part of the project and analysized different structures with different material parameters. A model for limiting the heat back flow in an operational device was investigated in detail and we are now performing computations on the energy flow in various devices. The Australian CI, C Zhang is scheduled to visit Lund University in April 2004. Other visits and collaborative activities have also been planned for the second half of 2004 and will be reported in the next progress report.

*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:** | 1 | CI | Prof SX Dou | University of Wollongong |
| | 2 | CI | Dr AV Pan | University of Wollongong |
| | 3 | OI | Prof TH Johansen | University of Oslo |
| **Collaborative Countries:** | Norway | | | |

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 stream-lines 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.

# Systemic Infrastructure Initiative Grants
# Department of Education, Training and Youth Affairs

*Nanofabrication facilities for processing of novel multilayer materials*

| | | | |
|---|---|---|---|
| **Years funded:** | 2002 | 2003 | 2004 |
| **Amount funded:** | $440,000 | $550,000 | $487.500 |
| **Institutions contribution:** | $192,500 | | |
| **Total funding:** | $1,670,000 | | |
| **Chief Investigators:** | Prof SX Dou, M. Ionescu, X.L. Wang, H.K. Liu, G.X. Wang<br>T. Silver, R.A. Lewis – University of Wollongong<br>A/Prof S. Ringer – University of Sydney<br>Prof GQM Lu – University of Queensland<br>Prof EM Goldys – Macquaire University<br>Prof M. M Wilson – UTS<br>A/Prof DN Jamieson, University of Melbourne<br>A/Prof J. Mazierska - James Cook University<br>Dr. J. Low - Curtin University of Technology<br>Dr. R. Ramer – UNSW<br>Prof. G. Smith – UTS<br>Prof. M. Skyllas-Kazacos - UNSW | | |

The proposal seeks to obtain nanofabrication facilities including a modified metallorganic chemical deposition (MOCVD), electron beam evaporation (EBE) and lithography facilities for the processing of novel multilayer materials and devices. These facilities will significantly enhance the national capacity in nanofabrication for a wide range of novel materials and devices.

# ARC Small & Near Miss Grants

***Magnetic shielding of superconducting wires and tapes by ferromagnetic sheath***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $15,000 | J. Horvat |

***Investigation of vortex dynamics in $Yba_2Cu_3O_7$ superconducting thin films deposited by pulsed-laser deposition technique at growth-controlled conditions***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $8,000 | Alexey Pan |

***In-situ production by spray pyrolysis method of nanocrystalline oxide materials for batter application***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $10,500 | Kostantin Konstantinov |

***Spectroscopic de4tection and novel treatment of surface and radiation damage in semiconductors***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $11,000 | Rodney Vickers & Peter Fisher |

***Improvement of critical current density in newly discovered $MgB_2$ through nano-SI doping***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $13,500 | Xiaolin Wang |

***Simulation of terahertz optoelectronics***

| **Amount funded:** | **Chief Investigator:** |
|---|---|
| $8,500 | Chao Zhang |

# University of Wollongong

*University Research Council, ISEM Performance Indicator& Management*

| **Year funded:** | 2003 | **Amount funded:** | $125,000 |
|---|---|---|---|

# Conferences

## 2nd International Polymer Batteries and Fuel Cells Conference, 1-6th June 2003, Shilla Hotel, Jeju Island, Sth Korea.

***New Approach for Synthesis of Carbon-Mixed $LiFePO_4$ Cathode Materials***

K. Konstantinov, S. Bewlay, G. X. Wang, M. Lindsay, J. Z. Wang, H. K. Liu, S. X. Dou and J-H. Ahn

For the first time, Carbon-mixed $LiFePO_4$ cathode materials have been prepared by spray solution technology. Nominal addition of 15 or 20 wt% C was used in order to simulate the industrial practice for preparation of electrode materials. The prepared powders consist of a single $LiFePO_4$ phase: small crystallites with a highly-developed surface area, beneficial for the surface electrochemical processes limited by the low Li diffusion. The combination of spray technology and C-addition increased the specific surface area above 20 $m^2/g$ at relatively high sintering temperature (700°C). The initial discharge capacity was up to 140 mAh/g compared to 125 mAh/g for conventionally prepared $LiFePO_4$ electrode materials.

## International Superconducting Electronics Conference, 7-11th July 2003 Sydney, Australia.

***Vortex depinning onset in YBCO superconducting films prepared under different conditions***

**A. V. Pan, M. Ionescu, S. X. Dou, V. S. Flis, V. A. Komashko and V. M. Pan**

A number of high quality $YBa_2Cu_3O_7$ thin superconducting films on different single crystal substrates has been prepared at different conditions using pulsed-laser deposition and magnetron sputtering techniques. The films obtained were investigated by magnetization measurements. Critical current density $J_c$ dependencies on the applied magnetic field $B_a$ were obtained. The analysis of the $J_c(B_a)$ behaviour obtained for the films suggests that the range of the $B_a$-independent plateau at low fields weakly depends on thin film structural parameters at temperatures ranging from the superconducting transition down to 4 K. Thermally activated vortex depinning is proposed to be mainly responsible for the onset of the $J_c(B_a)$ degradation at low fields.

## 11th International Workshop on critical Currents in Superconductors, 28-31st July 2003 Japan.

***Effect of nano-dopants and sample size on critical current density in the superconducting $MgB_2$***

**S.X. Dou, J. Horvat, X.L. Wang, A. Pan, S. Soltanian, S.H. Zou, S. Li, V. Braccini, X. Song, D.C. Larbalestier**

The nano-SiC doping into $MgB_2$ results in enhancement of $J_c$ in fields by more than an order of magnitude. The irreversibility field, $H_{irr}$, for the SiC doped samples reached 15T at 4.2K. $J_c$ for the best Si-Doped samples reached 40,000A/Cm$^2$ at 20K and 4T, and 20,000A/cm$^2$ at 5K and 10T. This large magnitude of enhancement is a resulf of combined effects of substitution and reaction which produce nano-intragrain pinning centres. TEM studyrevealed that nano-defect traps with extensive domain structure of a dimension of 2-5nm induced by the SiC doping may act as collective pinning in addition to the highly dispersed nano-precipitates. An extraordinary effect of sample size on magnetic $_c$ (H) was observed for bulk $MgB_2$. $_c$ decreased by more than two orders of magnitude at 7T and 5K, when the sample dimensions decreased from 7.15 x 3.27 x 1.07mm$^3$. At the same time, zero-field $J_c$ increased with decreasing sample size. A comparison

of magnetic $J_c(H)$ for samples of different size could lead to misleading conclusions if the samples are smaller than a few millimeters. The $J_c(H)$ determined by transport measurements is eliable because the sample is above this size. Different coupling between the superconducting grains at different length scales is proposed for the explanation of these results.

***The effect of sample size on magnetic $J_c$* and flux pinning in $MgB_2$**

**M.J. Qin, S. Soltanian and H.K. Liu**

The critical current density ($J_c$) derived from magnetic measurement in $MgB_2$ depends on the sample size has been observed. To compare with the larger size samples, smaller size samples showed higher $J_c$ at low fields and lower $J_c$ at higher fields. To explain this suprising results, the dependence of $J_c$ on the sample size has been derived as a power law $j \ \alpha \ R^{1/n}$ ($n$ is the $n$ factor characterizing $E$-$J$ curve $E = E_c(j/j_c)^n$). This dependence provides a new method to derive the $n$ factor and it can also be used to determine the dependence of the activation energy on the $J_c$. The SiC doped samples show less sample size effect than the pure samples, indicating a large $n$-factor and a stronger pinning effect due to SiC doping. $H_{irr}$ was observed to increase as a logarithmic function of the sample volume. A shift in the peak of the pinning force to lower magnetic fields was observed as the sample volume increased.

## NATO Workshop on Magneto-Optical Imaging, 28-31st August 2003 Øystese, Norway.

***Magneto-optical imaging of magnetic screening in superconducting wires***

**A. V. Pan and S. Dou**

Iron sheathed superconducting $MgB_2$ wires were investigated with the help of magneto-optical (MO) imaging technique in order to visualize local effects induced by ferromagnetic iron screen (sheath) into the superconducting $MgB_2$ core. MO experiments were also carried out in the wires with transport currents applied. The magnetic flux distribution within the superconducting core of the wire has been shown to be unusually modified in the case when the current is applied in the field-cooled state. The observed phenomenon is discussed in terms of magnetic interaction between the ferromagnetic screen and the superconducting core. This interaction enables a super-current redistribution within the core, so that the super-current paths are pushed to the middle of the core. This redistribution is consistent with the explanation of experimentally observed overcritical currents in the wires which are higher than the conventional critical current density.

***The optimization control of Bi-2223 superconducting tape fabrication procedure by magneto-optical imaging***

**M. Roussel, A. V. Pan, R. Zeng, H. K. Liu, and S. X. Dou**

A set of Ag-sheathed Bi-2223 ($Bi_{1.72}Pb_{0.34}Sr_{1.85}Ca_{1.99}Cu_3O_x$) tapes was produced using the powder in tube technique and two heat treatments separated by a mechanical deformation. For the second heat treatment, a two step annealing process was used with the first step at 825˚C and the second at different temperatures from 725 to 800˚C, an additional tape was produced by a slow cooling ramp after annealing at 825˚C. These tapes were studied by the way of magneto-optical imaging (MOI). This "local' technique provides results which correlate and clarify the results obtained by other "global" techniques (XRD, magnetization, critical current $J_C$, critical temperature $T_C$). The MO results show better superconducting properties (higher $J_C$, good shielding properties) for the slow cooled sample and for the sample which was annealed at 750˚C during the second step.

***Overcritical state as a result of magnetic interaction between iron sheath and $MgB_2$ core in superconducting tapes and wires***

**AV. Pan, S. Zhou, and S. Dou,**

The magnetic systems of superconducting wires and tapes, consisting of a magnesium diboride ($MgB_2$) superconducting core surrounded by a ferromagnetic iron (Fe) sheath, have been investigated. The interaction of the superconductor with the soft magnetic environment has been experimentally shown to lead to significant enhancement of dissipation-free super-current densities. The maximum densities of the super-currents can exceed the critical current densities obtained in the same ``*bare*" wire (with its iron sheath removed) by more than one order of magnitude under the same experimental conditions. This current density enhancement is referred to as the overcritical state which has been observed over a wide range of magnetic fields applied transversely to the wire. The origin of the observed phenomenon is discussed in terms of beneficial redistribution of the super-currents in the superconducting core as a result of the interaction between the $MgB_2$ superconductor and the magnetic environment of the sheath. No overcritical currents are observed for the longitudinal field orientation. The irreversibility field is shown to be considerably suppressed by the influence of the iron sheath for both field orientations. Round and flat wire cross sections have been investigated.

***Nature of high critical current density in HTS $YBa_2Cu_3O_{7-\delta}$ films***

**V. M. Pan, V. A. Komashko, V. L. Svetchnikov, C. G. Tretiatchenko, Yu. V. Cherpak, A. V. Pan, S. X. Dou, E. A. Pashitskii, S. M. Ryabchenko, A. V. Semenov, Yu. V. Fedotov, H.W. Zandbergen**

By highly advanced structural analysis, HTS YBCO films have been shown to form the nano-scale network of low-angle domain boundaries (LABs), consisting of natural linear defects (out-of-plane edge dislocations). The domains are 30-300 nm large and misoriented by ~1°. The average in-plane density of dislocations is up to $10^{11}$ $cm^{-2}$. LABs are quite ordered rows of parallel dislocations capable of providing strong pinning for vortices because the dislocations have non-superconducting cores surrounded by localized regions of suppressed $T_c$. However, supercurrent density can be limited by transparency of the dislocations, determining the effective depairing current density, whereas gaps between dislocations would remain transparent for supercurrent flow across LABs. As a consequence, two $J_c$-limiting mechanisms governed by depairing/transparency and by depinning can be anticipated. The variation of linear defect density and defect spatial distribution would lead to the realization of a certain $J_c$-limitation mechanism. Magnetic field, angular and temperature dependencies of $J_c(H,T)$ have been measured by SQUID magnetometer, ac susceptibility and dc transport current techniques in YBCO films, epitaxially-grown by off-axis dc magnetron sputtering, having $J_c(77\ K) > 2\ MA/cm^2$. The model of vortex depinning from linear defects has been developed and shown to well describe the measured $J_c(H,T)$ quantitatively. The model takes into account a statistic distribution of dislocation domain sizes, as well as interdislocation spacing within boundaries. On the other hand, the crossover of $J_c(H)$ from a plateau-like behavior at $H \rightarrow 0$ to its logarithmic degradation at higher fields can indicate the existence of the transparency-controlled $J_c$-limitation in the low-field region.

***Effects of Si and C doping on the superconducting properties of $MgB_2$***

**S.H. Zhou, A.V. Pan, M.J. Qin, X.L. Wang, H.K. Liu, S.X. Dou**

C and Si powders with different sizes were doped into $MgB_2$ separately or together. Samples were made by a solid-state reaction method. Mg powder and amorphous B powder were used for making $MgB_2$ bulk sample. 10%(wt) doping materials were mixed with Mg and B powders. The mixtures were pressed into pellets with a diameter of 10mm. The pellets were sintered at 750°C for 0.5 hr. It was found that the C doping has strong negative effect on critical temperature ($T_c$) while Si doping did not change $T_c$ too much. All of these doping materials increased $_c$ at higher field and higher temperature when the doping particles were of nanometer sizes. At 20K and 4T, $J_c$ of the sample doped with C and Si powders with nanosizes achieved $10^4$A/Cm$^2$, which is 5 times higher than that of undoped $MgB_2$. However, when dopant particles were as large as μm the doping has no obviously beneficial effects of the $J_c$.

***Control of nano-structure for enhancing flux pinning in the superconducting $MgB_2$ through chemical doping***

**S.X. Dou, J. Horvat, X.L Wang, M.J. Qin, A. Pan, M. Ionescu, S. Sotanian, S.H. Zhou, H.K. Liu, P. Munroe, S. Li and D.C. Larbalestier**

Further development and growth of the newly discovered $MgB_2$ depends on the solution of fundamental materials and fabrication problems directed towards increases in flux pinning and critical current density ($J_c$). A wide range of chemical doping, including C, Si, SiC, BN etc has been used to improve the flux pinning properties in $MgB_2$. The effect of doping on phase relationship, crystallography, superconductivity and flux pinning will be discussed in details. The nano-SiC doping into $MgB_2$ results in enhancement of $J_c$ in fields by more than an order of magnitude. The irreversibility field, $H_{irr}$, for the SiC doped samples reached 15T at 4.2K. $J_c$ for the best SiC-doped samples reached 60,000A/cm$^2$ at 30K and 1T, 40,000A/cm$^2$ at 20K and 4T, and 20,000A/cm$^2$ at 5K and 10T.

These results represent one of the most significant advancements since the discovery of the superconductivity in $MgB_2$. TEM study revealed that nano-domain structure with a dimension of 5nm induced by the SiC doping may be effective pinning centres in addition to the highly dispersed nano-inclusions of precipitates. The chemical doping is readily available and scalable technique for long $MgB_2$ wire production.

***Fabrication and Superconductivity of Buli $MgB_2$ sample prepared by hot pressing and in-situreaction***

**S. Soltanian, X.L. Wang, J. Horvat, S.X. Dou**

$MgB_2$ polycrystalline bulk samples were prepared using hot pressing and in-situ reaction. The new technique was developed to make samples using the Gleeble Machine. Samples were sintered in Ar at temperatures between 750 to 950°C for 3-40 min using several different temperature, time and pressure profiles. Samples were prepared with a variety of different densities. They were charactersed by X-ray diffraction (XRD), scanning electron microscopy (SEM) and magnetic measurements. Results show that all the samples are single phase with average grain sizes of about 250 nm. The $J_c$ and the $J_c$ field dependence for all samples are also presented. It was found that $J_c$ increases as the density of samples increases. However, high temperature and longer sintering times did not improve $J_c$. Comparisons of $J_c$ and flux pinning are made between the hot pressed sample and those made by in-situ reaction under ambient pressure.

## International Conference on Terahertz Optoelectronics, Sendai, Japan, 23-27th September 2003

***Free carrier terahertz magneto-absorption in semiconductor heterostructures***

**C. Zhang**

Terahertz radiation plays an important role in probing and studying the optical and transport properties of low dimensional semiconductor systems. Because of the nearly resonant match between the phonton energy (of order of THz) and all characteristic energies of the electronic system such as Fermi energy, phonon energy, subband energy etc, (all of order of meV or a few THz), the electronic system can exhibit various resonant and nonlinear phenomena. Under simultaneous application of a quantizing magnetic field and a terahertz electrical field, magneto-photon resonance and nonlinear magneto-absorption can occur.

In this work we report a theoretical and numerical study of nonlinear electrical current and free carrier magneto-absorption in semiconductor heterostructures driven by an intense terahertz laser. We solve the density matrix of electrons localized in Laudau levels and scattered by random impurities. These density matrices include all orders of multi photon emission and absorption processes[1]. The quantum transport equations[2] were solved and the nonlinear electrical current density can be written as,

$$J(\omega,\omega_c)= \sum_{mm'} J^{mm'}(\omega,\omega_c)$$

where $J^{mm'}$ is the current density due to electron-impurity scattering involving transitions of m Laudau levels and absorption of m′ photons. The real part of the current determines the free carrier absorption. Numerical simulations were performed and it is found that Joule heating of the electronic system due to impurity scattering decreases rapidly due to the strong electron-photon interaction. Our result is the dynamic equivalence of electron localization in a strong field. Magneto-photon resonance involving multiple photons can be easily identified in our result.

[1] M. Fujita, T. Toyota, J. C. Cao, and C. Zhang, Phys. Rev. B67, 075105 (2003)
[2] C. Zhang, Phys. Rev. B66, 081105(R) (2002)

## International Conference on Infrared and Milimeter Waves, Otsu, 29th September – 2nd October 2003 Japan

***Nonlinear absorption of THz waves in semiconductor heterostructures***

**C. Zhang and S. Hessami Pilehrood**

By using a formalism based on quantum transport equation, we study the current response of an electron gas strongly coupled to an intense terahertz laser. The effect of laser is treated exactly which gives rise to the electron-photon side-bands. Our formalism includes up to the second order in electron-impurity scattering and to any order in optical transitions between the side-bands. Resonant scattering can occur when the frequency of the probing field equals the multiple of terahertz laser frequency. The usual linear response theory is the zero-photon term in our formalism. This result can be applied to study the electrical transport in strongly coupled electron-photon systems. One of such systems is a two-dimensional semiconductor structure under an intense terahertz radiation

## 8th IUMRS International Conference on Advanced Materials 8-13th October 2003 Yokohama Japan

***Effect of nano-carbon tube doping on critical current density of $MgB_2$ superconductor***

**S.X. Dou, W.K. Yeoh, J. Horvat, M. Ionescu**

Effect of doping of nano-carbon tubes on transition temperature, lattice parameters, critical current density and flux pinning were studied for $MgB_{2-x}C_x$ with x = 0, 0.05, 0.1, 0.2 and 0.3. The depression of $T_c$, which is caused by the carbon substitution for B, increases with increasing doping level, sintering temperature and duration. By controlling the extent of the substitution and addition of carbon nanotubes we can achieve the optimal improvement on critical current density and flux pinning while maintaining the minimum reduction in $T_c$. Under these conditions, $J_c$ was enhanced by two orders of magnitude at 8T and 5K and 7T and 10K. $J_c$ was more than 10,000A/cm$^2$ at 20K and 4T and 5K and 8.5T respectively. The mechanism for the flux enhancement will be discussed.

*1.5KA AgAuMg sheathed Bi-2223 HTS Current Leads*

**R. Zeng, H.K. Liu, F. Darmann, M. Apperley**

1.5KA class high temperature superconducting (HTS) current leads were manufactured and tested. The HTS current leads were constructed by bounding of Ag, AgAu and AgAuMg alloy sheathed tapes, non-magnetic stainless steel former and copper caps. Doping alloy effects on microstructure, processing, electrical, mechanical and thermal properties of Ag-alloy sheathed Bi2223 tapes have been analyzed and estimated. The measured critical current of the HTS current leads was 1540A, 1346A and 980A for AgAuMg, AgAu and Ag sheathed Bi-2223 current leads at 77K, respectively. Using a mass flow loss measurement instrument, heat leak was estimated to be 2.4W, 1.1W and 1.0W/lead when the temperature was from 77K to 300K. Using experience formula of thermal conductivity, the heat leak was estimated calculated to be 9W, 0.21W and 0.20W/lead when the warm end temperature was 77K.

## SPIE's International Symposium on Microelectronics, MEMS, and Nanotechnology 10-12th December 2003 Perth Australia

***Nonlinear free carrier absorption in semiconductor heterostructures in terahertz regime***

**C. Zhang and S. Hessami Pilehrood**

Absorption of electromagnetic waves in electronic systems coupled to intense terahertz waves is calculated. We formulate a theoretical framework suitable for calculating the frequency-dependent electrical current under an intense THz radiation. This first principle method is based on the time-evolution of electron density matrix and it includes electron-photon coupling to all orders. We first obtained the time-dependent electronic states as a function of terahertz field and frequency. The electron-impurity scattering is included to the second order. The absorption of electromagnetic waves of a probing field via various electron-terahertz-photon coupling is then obtained in terms of frequency-dependent dielectric functions.

# Invited Speaker Presentations / Seminars

Shanghai Institute of Microsystems and Information Technology, Chinese Academy of Science, 1st March 2003

**C. Zhang**

***Density matrix formalism for nonlinear electrical transport***

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7th International Conference on Materials and Mechanisms of Superconductivity and High Temperature Superconductors 25-30th May 2003,

**X.L. Wang**

*Significant enhancement of flux pinning in $MgB_2$ with nano-SiC, Si, or C addition*

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Department of Physics, Pohong University Science and Technology, Republic of Korea, June 2003

**X.L. Wang**

*Spin glass, spin and charge ordering, and magnetoresistance in perovskite transition metal oxides*

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National Creative Research initiative center for superconductivity and Department of Physics, Pohong University Science and Technology, Republic of Korea, June, 2003

**X.L. Wang**

*Significant improvement of critical current density in $MgB_2$ bulks and metal sheathed wires/tapes by nano-particle doping and very short-time in-situ reaction*

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HTS wire Lab, Materials Technology Department, Korea Institute of Machinery and Materials, Korea, June, 2003

**X.L. Wang**

*Significant enhancement of flux pinning in $MgB_2$ with nano-addition*

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Department of Materials Engineering, Andong National University, June 2003. Korea

**X.L. Wang**

*Colossal Magneto-resistance Materials*

National Institute for Materials Science, Japan, July 2003

**X.L. Wang**

Significant enhancement of flux pinning in $MgB_2$ with nano-addition and short-time in-situ reaction

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Kyusu Insitute of Technology, 25th July 2003

***Critical current and flux pinning of $MgB_2$***

**S.X. Dou**

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11th International Workshop on critical Currents in Superconductors, July 28-31, 2003, Japan.

**S.X. Dou**

***Effect of nano-doping on critical current density in superconductor $MgB_2$***

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8th IUMRS International Conference on Advanced Materials 8-13 October 2003) Yokohama Japan

**S.X. Dou**

***Effect of nano-carbon tube doping on critical current density of $MgB_2$ superconductor***

# Seminars by Visiting Scientists

| Date | Name | Institute | *Title* |
|---|---|---|---|
| 13th Feb | Prof. J.Y. Lee | Korea Academy of Science & Technology, Korea | Effects of iron substitution for nickel on the electrochemical properties of $LiNi_{0.8-x}Fe_xCo_{0.2}O_2$ |
| 21st Feb | Dr. E.W. Collings | Ohio State University, USA | Niobium-Aluminum superconductor development for high field applications |
| 20th Mar | Prof. E.S. Otabe | Institute of Technology, Japan | Superconducting transformer cooled by cryocoolers<br>AC loss estimated by FEM<br>Third harmonic voltage analysis by FEM<br>Condensation energy density in Bi-22212<br>Wide range of E-J in coated conductor |
| 30th May | Dr. G. Alvarez | | Single electron effects in NBCO/PBCO/NBCO tunnel junctions |
| 8th Jul | Prof J.Y. Lee | Korea Advanced Institute of Science & Technology | The improvement of cycle life of Ti-based alloy electrodes of Ni-Mh rechargeable batteries |
| 11th Jul | Dr. R.A. Robinson | The Bragg Institute, Australia | Opportunities for physics research at Australia's replacement research reactor |
| 11th Jul | Prof. H.E. Horng | National Taiwan Normal University, Taiwan | Ordered structures with defects in magnetic fluid films for photonic crystals |
| 16th Jul | Mr M. Song | Korea Advanced Institute of Science & Technology | The effects of nano-sized adsorbing materials on the electrochemical properties of sulfur cathode for lithium/ sulfur batteries |
| 17th Jul | Dr Ling Hao | CSIRO, Australia | New directions for AQUID applications |
| 22nd Jul | Prof J.Y.Lee | Korea Advanced Institute of Science & Technology | Preparation and electrochemical properties of lithium-sulfur polymer batteries |
| 24th Jul | Y.M. Kang | Korea Advanced Institute of Science & Technology | A study of the electrochemical properties of $Co_3O_4$ and Ni-$Co_3O_4$ composites for an anode material of Li-ion batteries |

| Date | Name | Institute | *Title* |
|---|---|---|---|
| 5th Aug | Prof. K.A. Chao | Lund Univesity, Sweden | Cool Chips |
| 7th Aug | Prof J.Y.Lee | Korea Advanced Institute of Science & Technology | A study of the electrochemical properties of Si-C for an anode material of Li-ion batteries |
| 14th Aug | Prof J.Y.Lee | Korea Advanced Institute of Science & Technology | A study on the delayed fracture characteristics of high strength bolt steels by hydrogen thermal desorption analysis |
| 22nd Aug | Dr D. Shi | University of Cincinnati, USA | Synthesis and transport properties of YBCO thin films deposited by a fluorine-free solution method |
| 27th Nov | Prof A.D. Caplin | Imperaial College, London, UK | The present state of the art and visions for $MgB_2$ |
| 1st Dec | Prof J Wang | Tianjin Institute of Power Sources, China | Recent developments in Li-ion batteries |
| 17th Dec | Prof. M. Changyun | Tianjin Polytechnic University, China | A short introduction to Tianjin University and the School of Informationa nd communications |
| 17th Dec | A.Prof. P. Niu | Tianjin Polytechnic University, China | RTD & HPT monolithic optoelectronic integration |
| 17th Dec | Prof. X. Sun | Northeastern University, China | Synthesis of ceramic nanopowders for high-performance ceramics |

# Equipment and Facilities

ISEM facilities contain 9 laboratories with a floor space of approx 420m$^2$ 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:

| | |
|---|---|
| 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 and Dr I. Low |
| James Cook University | Prof J Mazierska |
| Macquarie University | A/Prof E Goldys |
| Monash University | Dr YB Cheng  Dr. R. Krishanmurthy |
| University of Melbourne | A/Prof DN Jamieson |
| University of NSW | Prof M Skyllas-Kazacos, Dr R. Ramer |
| University of Queensland | Prof. M.G. Lu, Prof D.R. Mackinnon |
| University of Sydney | A/Prof S Ringer, Dr V Keast |
| University of Technology, Sydney | Prof J. Smith and Prof J.N. Bell, |
| | 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 glovebox
-

**Thin Film Deposition Facility**

- Excimer laser, ComPex301, 9W, 10Hz, 248nm
- Thin Films Depositon Chamber, 18" dia. With high vacuum system

**Materials Characterisation**

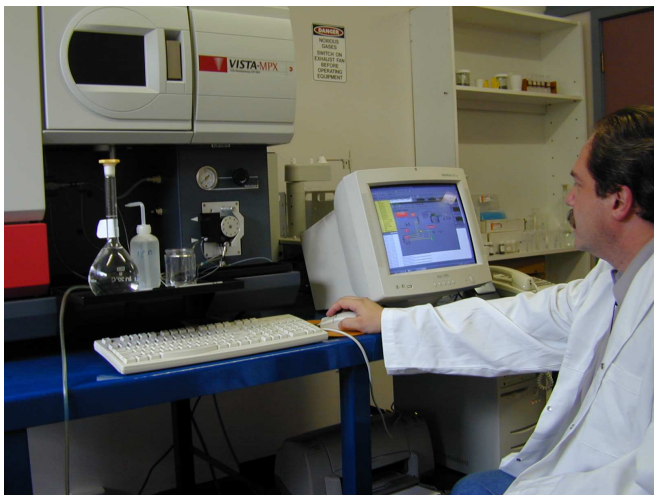
- DTA/TG, Setaram, 18-92, 1750°C
- XRD for Single Crystals
- TEM, J2000FX1, with EDS
- Gas absorption analyzer Nova 1000 for BET and pore size analyses
- XRD, M18XHFCu with HT 2000°C camera
- SEM, Stereoscan 440, with EDS and EBSP
- AFM, Nanoscope IIIa
- Particle Size Analyser, Mastersizer S, 0.05-900µm
- XRD, PW1050, 3kW; XRD Texture, PW1078, 3kW
- DSC, TA300,-170°C+600°C

**Physical Property Characterisation**

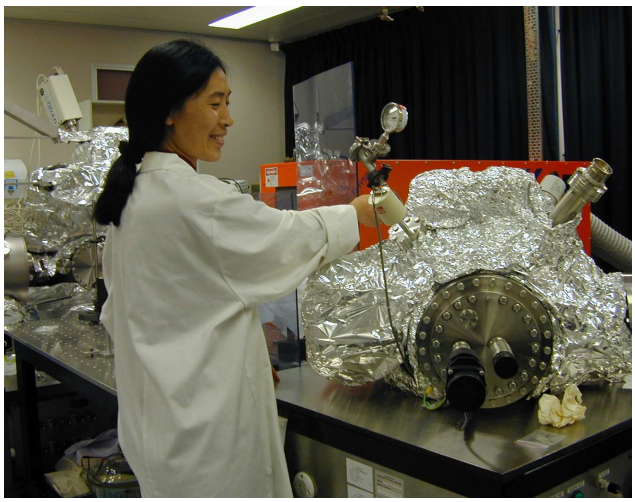
- MPMS, 4-400K, 0-5T DC field
- PPMS, 2-400K, 0-9T DC field
- Horizontal field superconducting Magnet, 0-8T, 5-300K
- Lock-in Amplifier, SR510; Lock-in Amplifier, SR830DSP, 2 x PAR 5209 Lock-in Amplifier, PAR 124 Lock-in Amplifier
- Magneto Optical Imaging, 12K-300K
- Electromagnet, HSV-4H1, 2T, 100mm 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 Teslameter, DTM-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
- Lasers, Spectra Physics Model 2040 25 W $Ar^+$, Spectra Physics Model 165 6 W $Ar^+$, Spectra Physics Model 3900 Titanium-sapphire, Spectra Physics Model 380 Dye, Spectra Physics 15 mW HeNe
- 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 L He storage, 30 l L He storage, 60 l L N storage, 50 l 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

**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
- 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

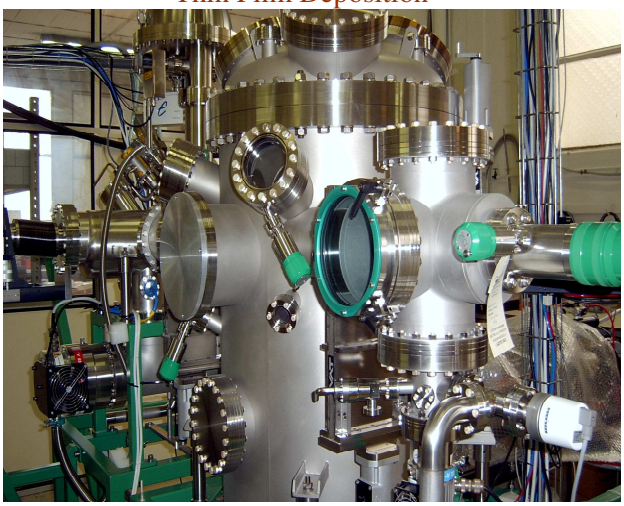



ICP-OES, Vista Simultaneous
Axial Spectrometer

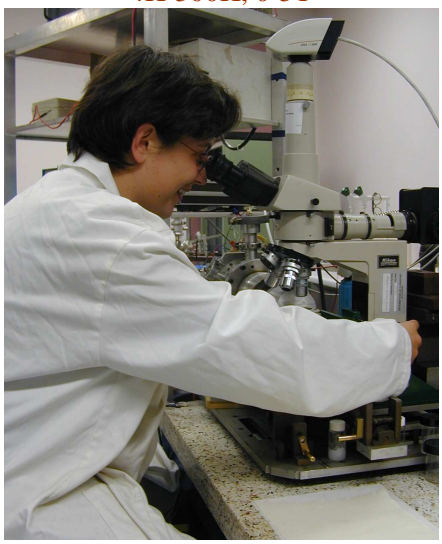


Excimer Laser Ablation System for
Thin Film Deposition

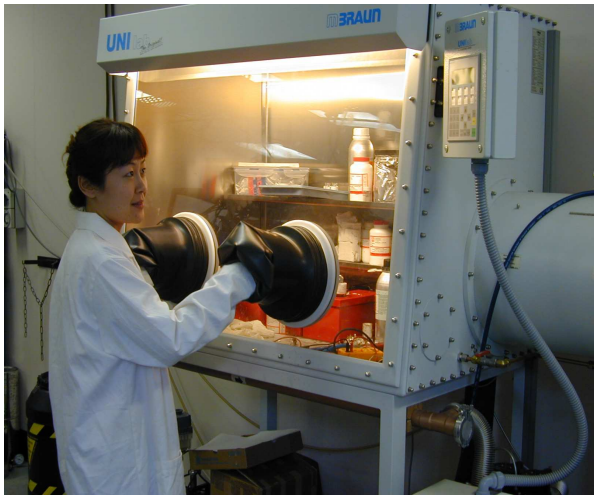
Magnetic Property Measurement System
4K-300K, 0-5T



Electron Beam Evaporation Facility



Magneto-Optical Imaging with
Cryocooler from 12K to 300K




Glovebox for Creating Oxygen and
Moisture free Environment

# Refereed Publications

Book Chapters

S.X. Dou "High $T_c$ conductor processing techniques", *Handbook of Superconducting Materials*, (421-448) ed. D Cardwell, University of Cambridge, UK; D. Ginley, NREL, USA, IoP, (2003)

P.N. Mikheenko, K.K. Uprety and S.X. Dou, "High Temperature Superconductors, C2. BSSCO", *Handbook of Superconducting Materials*, (947-992), ed. D Cardwell, University of Cambridge, UK; D. Ginley, NREL, USA, IoP (2003)

Journal Articles

J.H. Ahn, G.X. Wang, H.K. Liu and S.X. Dou "Nanoparticle-dispersed PEO polymer electrolytes for Li batteries" *J. Power Sources* **119-121**, 422-426 (2003)

J.H. Ahn, G.X. Wang, J. Yao, H.K. Liu and S.X. Dou "Tin-based composite materials as anode materials for Li-ion batteries" *J. Power Sources* **119-121**, 45-49 (2003)

W.M. Chen, W. Chen, S.H. Zhou, H.Y. Ling and S.S. Jiang "Pressing processing diminishes outgrowth and bridging for AgMg/Bi-2223 tapes" *J. of Supercond.* **16, 3,** (495-499 (2003)

Y. Chen, G.X. Wang, K. Konstantinov, J.H. Ahn, H.K. Liu and S.X. Dou "Studies of the electrochemical properties of nanosize $Co_3O_4$ oxide as an anode material for lithium-ion batteries" *J. Metasable and Nanocrystaline Mat.* **15- 16**, 625-628 (2003)

Y. Chen, G.X. Wang, K. Konstantinov, H.K. Liu and S.X. Dou "Synthesis and characterisation of $LiCo_xMn_yNi_{1-xy}O_2$ as a cathode material for secondary lithium batteries *J. Power Sources* **119-121**, 184-188 (2003)

E.W. Collings, E. Lee, M.D. Sumption, M. Tomsic, X.L. Wang, S. Soltanian and S.X. Dou "Continuous- and batch processed $MgB_2$/Fe strands – transport and magnetic properties" *Physica C* **386**, 555-559 (2003)

F. Darmann, S.X. Dou and C. Cook "Determination of the AC losses of Bi-2223 HTS coils at 77K at power frequencies using a mass boil-off calorimetric technique" *IEEE Trans. On Appl. Supercond.* **13, 1** 1-6 (2003)

S.X. Dou, J. Horvat, S. Soltanian, X.L. Wang, M.J. Qin, S.H. Zhou, H.K. Liu and P.G. Munroe "Transport critical current density in Fe-sheathed nano-SiC doped $MgB_2$ Wires" *IEEE Trans. On Appl. Supercond.* **13, 2** 3199-3202 (2003)

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S.X. Dou, W.K. Yeoh, J. Horvat and M. Ionescu "Effect of carbon nanotube doping on critical current density of $MgB_2$ superconductor" *App. Phys. Lett*. **83, 24** 4996-4998 (2003)

P. Fisher, R.E.M. Vickers and K. Ishida "Coulomb related Landau spectra of axial and double acceptors in germanium" *Phys. Stat. Sol.* **0,2,** 683-686 (2003)

P. Fisher, R.E.M. Vickers and D.C. Lau "Bulk homogeneous uniaxial stress arising from surface damage of crystalline silicon and germanium" *Surface Rev. and Lett.* **10, 2 & 3** (2003)

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J. Wang, S. Zhong, H.K. Liu and S.X. Dou "Beneficial effects of red lead on non-cured plates for lead-acid batteries" *J. Power Sources* **113**, 371-375 (2003)

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S. Zhou, H.K. Liu, J. Horvat and S.X. Dou "Effect of Ti doping on the superconducitivites of MgB2/Fe Wires" *J. Low. Temp. Phys.* **131**, **3/4**, 687-692 (2003)

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S.H. Zhou, A.V. Pan, M.J. Qin, H.K. Liu and S.X. Dou " Effect of the processing parameters of $MgB_{1.8}(SiC)_{0.1}$/Fe tapes on the critical current density" *Physica C* **387**, 321-327 (2003)

Conference Proceedings

C. Freeth and R.A. Lewis "Far-infrared laser magnetospectroscopy of Donors and Acceptors in Ge" *Proc. 27th Annual A&NZIP Cond. Matt. & Mat. Meeting*, 4-7/2/2003, Wagga Wagga, Australia (2003)

C. Freeth and R.A. Lewis "Selective laser excitation spectroscopy of gallium and phosphorous in germanium" *Conf. on Optoelectronic and Microelectronic Materials and Devices*, 11-13/12/2002, Ed: M. Gal, IEEE Publishing, 447-450 (2003)

R.A. Lewis, Y.-J. Wang and M. Henini "Magnetospectroscopy of the C line of Be in GaAs" *Proc. 27th Annual A&NZIP Cond. Matt. & Mat. Meeting*, 4-7/2/2003, Wagga Wagga, Australia (2003)

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B.C.C. Lough, S.P. Lee, Z. Dou, R.A. Lewis and C. Zhang "Thermal and electrical characteristics of a multilayer thermionic device" *Proc. Of Optoelectronic and Microelectronic Materials and Devices*, 11-13/12/2002, Ed: M. Gal, 511-514 (2003)

A.V. Pan, S. Zhou, H.K. Liu and S.X. Dou "Overcritical state in Fe-sheathed $MgB_2$ superconductor wires" *Proc. 27$^{th}$ Ann. A&NZIP Cond. Matt. And Mat. Meet.* 4-7/2/2003, Ed: J. Cashion, T. Finlayson, D. Paganin, A. Smith and G. Troup, (2003)

W. Xu, R.A. Lewis, P.M. Koenraad, L.R.C. Waumans and C.J.G.M. Langerak "Magnetophoton-phonon scattering in two-dimensional electron gases" *Condensed Matter Theories*, **17** 373-382, Proc. 25$^{th}$ Int. Workshop on Condensed Matter Theories, 3-9/12/2001, Ed: M.P. Das, F. Green (2003)

C. Zhang "Terahertz-driven nonlinear electrical transport in semiconductor nanostructures" *Proc. Of Optoelectronic and Microelectronic Materials and Devices*, 11-13/12/2002, Ed: M. Gal, 405-408 (2003)

# Funding 2003

## Australian Research Council Grants

ARC Large/Discovery Scheme Grants

| | | | |
|---|---|---|---|
| S.X. Dou | Enhancement of transport Jc in magnetic field of Ag/BiPbSrCaCuO tapes by fission tracks | $83,178 | |
| S.X Dou, J. Horvat | First principles for development of high temperature superconducting wires | $244,531 | |
| X.L. Wang | Enhancement and elucidation of flux pinning in doped Bi-Sr-Ca-Cu-O high temperature superconducting single crystals | $65,822 | |
| X.L. Wang | Magnetoresistance, charge and spin ordering in Transition Metal Oxides | $92,066 | |
| H.K. Liu | Growth, characterisation and flux pinning behaviour of doped $TiSr_2Ca_2Cu_3O_y$ and $TiSr_2CaCu_2O_y$ and high temperature superconducting single crystals | $62,383 | |
| C. Zhang | Analysis, simulation, fabrication and characterization of reliable, robust and scalable compact cooling elements based on semiconductor nanostructures | $75,000 | **$622,980** |

### ARC Fellowship Scheme Grants

| | | | |
|---|---|---|---|
| H.K. Liu | ARC Professorial Fellow, Optimisation of thermal & mechanical Processing & critical current density High $T_c$ superconducting ag-clad Bi(Pb)SrCaCuO Tapes | | **$113,000** |

### ARC Linkage Projects & Linkage APAI

| | | | |
|---|---|---|---|
| X.L. Wang | Fabrication of magnesium diboride ($MgB_2$) thick films | $22,545 | |
| S.X. Dou, GX. Wang | Developing new cathode materials for lithium-ion batteries using Australian mineral resources | $84,000 | |
| S.X. Dou, X.L. Wang, M.Ionescu | Fabrication and characterisation of magnesium diboride superconducting wires | $100,000 | |
| H.K. Liu, S. Zhong | Investigation of nano-materials for use in lithium rechargeable batteries | $62,000 | |
| R. Lewis, C. Zhang | Experimental development of thermionic cooling for domestic refrigeration | $22,292 | |
| G.X. Wang, H.K. Liu, S. Zhong | Solid-state rechargeable lithium batteries for telecommunication and portable electronic devices | $63,922 | **$354,759** |

### Linkage International Awards

| | | | |
|---|---|---|---|
| R.A Lewis, C. Zhang | Development of solid-state cooling chips | $9,500 | |
| H.K. Liu, D. Shi | Investigation of a series of metallic substrate materials suitable for developing long Y-Ba-Cu-O superconductors | $17,596 | **$27,096** |

**Total this page** **$1,117,835**

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|---|---|---|---|
| **Brought forward** | | | **$1,117,835** |

## Systemic Infrastructure Initiative Grants

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|---|---|---|---|
| S.X. Dou et al | Nanofabrication facilities for processing of novel multiplayer materials | | **$487,000** |

## Small Grants & Indicative Near Miss Grants

| | | | |
|---|---|---|---|
| J. Horvat | Magnetic shielding of superconducting wires and tapes by ferromagnetic sheath | $15,000 | |
| A. Pan | Investigation of vortex dynamics in $Yba_2Cu_3O_7$ superconducting thin films deposited bypulsed-laser deposition technique at growth-controlled conditions | $8,000 | |
| K. Konstantinov | In-situ production by spray pyrolysis method of nanocrystalline oxide materials for batter application | $10,500 | |
| R. Vickers & P. Fisher | Spectroscopic de4tection and novel treatment of surface and radiation damage in semiconductors | $11,000 | |
| X.L. Wang | Improvement of critical current density in newly discovered $MgB_2$ through nano-SI doping | $13,500 | |
| C. Zhang | Simulation of terahertz optoelectronics | $8,500 | **$65,500** |

## Australian Institute of Nuclear Science & Engineering

| | | | |
|---|---|---|---|
| D. Marinaro/SX Dou | Special Postgraduate Award | $5,500 | |
| T.Silver | Thermal neutron irradiation of uranium-doped superconductors | $1,710 | |
| X.L. Wang | Studies of novel perovskite cobalt compounds | $10,818 | |
| X.L. Wang | Studies of magnetic properties of doped Y-Sr-Co-O perovskite cobalt compounds | $27,818 | |
| X.L. Wang | Enhancement of critical current density in newly discovered $MgB_2$ superconductors using hot isostatic press and hot press techniques | $2,300 | **$48,146** |

## Industry Grants

| | | |
|---|---|---|
| Metal Manufactures Ltd | $110,000 | |
| Lexel Battery Co Ltd | $19,500 | |
| Sons of Gwalia Ltd | $30,000 | |
| Hyper Tech Research Inc | $20,000 | |
| Australian Battery Technology Ltd | $15,000 | |
| OMG Group | $10,000 | |
| Alphatech International Ltd | $6,000 | |
| FSL Enterprises Ltd | $5,000 | **$215,500** |

## University of Wollongong Support

| | | |
|---|---|---|
| ISEM Performance Indicators | $125,745 | |
| Faculty of Engineering funding | $20,000 | |
| ISEM Management Fund | $75,000 | |
| URC contribution | $76,000 | |
| Postgraduate student maintenance funds | $22,000 | |
| Scholarships | $189,000 | **$507,745** |
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