Contents

Welcome to ACES

ACES is the Australian Research Council (ARC) Centre of Excellence for Electromaterials Science. It brings together eminent scientists to develop the nano-science and nano-technology related to the movement of electric charge within and between materials. The approach provides an alternative to varying the composition of a material to alter physical and biological properties – instead we alter dimensions and shape in the nanodomain. These processes are fundamentally important to a diverse array of phenomena important in medicine and industry. ACES is studying these processes and, in so doing, is developing improved electromaterials and applying these in energy harvesting systems and highly efficient energy storage materials.

Through the investigation of new nanomaterials and new theories to explain their behaviour, ACES will tackle some of the biggest challenges facing society. These include the development of renewable energy systems in the form of plastic solar cells, lightweight batteries and electronic textiles: the growth of sustainable industries which would benefit from advances in the recovery of precious metals and new corrosion protection technologies; advances in medical science through the regeneration of damaged nerves such as in spinal injury; and the development of artificial muscles.

ACES is made up of components from four research organisations: the University of Wollongong (including the Intelligent Polymer Research Institute and the Institute for Superconducting & Electronic Materials), Monash University (including the Ionic Liquids group), the Bionic Ear Institute and St Vincent's Health in Melbourne.

ACES was established in 2005 and is funded by the ARC with $12 million in federal funding over five years. ACES also receives support from the NSW Department of State & Regional Development to achieve technology transfer to NSW and Australian industry.

This 2007 Annual Report is a part of the Centre's reporting requirements and sets out the Centre's achievements for the 2007 calendar year. It reports on the progress made by the Centre's four main research programs: Electromaterials (P1), Energy conversion (P2), Energy storage (P3) and Bionics (P4). It also discusses progress in several other areas in which the Centre is active (such as ethics, education and outreach).

ACES was established to bring together eminent scientists to develop the nano-science and nano-technology related to the movement of electric charge within and between materials.

From the Executive Research Director

INTEGRATION

- Integration of ideas and skills
- Integration of the research team across the Centre nodes
- Integration with End Users
- Integration with the international research community
- Integration with the scientific and general community in Australia

The design, development and discovery of new electromaterials and the use of them in energy conversion, storage and medical bionics is the crux of our research. We have begun to achieve our goals by addressing the issue of effective integration at all levels of our activities.

Achieving our goals requires an integration of ideas, skills, personalities, infrastructures and support facilities in an effective manner. Internal integration needs to be matched with ACES working effectively within an appropriate End Users network both domestically and internationally. High level contributions to the international scientific research community require careful integration on the global scale.

During 2007 we have added to the ACES team and built a research capability of world class standard. Along with some of the world's leading scientists, we have attracted experienced, dedicated administrators and advisors of the highest calibre. I am particularly honored to be able to welcome Dame Bridget Ogilvie as the new Chair of our International Advisory Board from 2008. These added skills and improved facilities have provided new dimensions to our research and are uncovering new opportunities. We have a unique research opportunity created by the highly talented individuals that make up ACES. These individuals have been attracted from around the world, for example, 14 PhD students from 10 different countries enrolled with ACES in 2007. There is no doubt the unique insights and approaches arising from such individuals will further enhance the outputs and profile of ACES to the benefit of Australia.

During 2007 we have consolidated our innovative research training programs with researchers given opportunities to share and acquire new skills via an array of workshops, ACES Centre meetings and our Annual International Symposium. Regular exchange of researchers between sites ensures exposure to other facilities and expertise and provides exciting new training opportunities for both early career researchers and PhD students.

ACES End User links continue to grow with collaborative work now underway with BlueScope Steel, Visiocorp and CAP-XX in Australia. ACES researchers play critical roles in two Victoria Government STI initiatives: Bionic Technologies Australia and VICOSC, a venture aimed at commercializing aspects of solar cell research. ACES staff also work on collaborative projects supported by the CRC Polymers, DSTO and CSIRO. As ACES becomes recognized as the National Centre for Electromaterials Research, other companies requiring assistance and advice are drawn to our Centre on a regular basis. ACES also provides a focus for new End Users keen to be aware of the international state-of-the-art in their particular area. The integrated domestic and international research network that has been established provides exciting opportunities to develop new linkages and utilise the expertise and insights of others to provide outputs amplified by synergies.

Interest in nanotechnology and in our contribution as well as use of it within Electromaterials Science has drawn significant attention from the general community. Our ability to generate new electrodes for energy and bionics attracted attention from the print, radio and TV media. ACES has provided comments as well as feature stories on nanobionics, solar cells, breakthroughs in nanofabrication and ethical issues arising from nanotechnology. ACES staff are actively involved in public lectures, special addresses to high schools and in the engagement of undergraduate students in our research. ACES researchers have engaged in public fora on **Energy Options** and another on **Health Options for 2020** organized by the Wollongong Science Centre.

At a number of levels the ACES executive team has highlighted the importance and benefits of integration. Efficient integration of a multidiscipline, multi-skilled and multi-personality research team gives us an exciting opportunity to continue to deliver cutting edge research; research that will impact on a range of End Users, research that will confront conventional thinking and approaches.

On a personal note, the importance of team integration, the excitement and level of innovation that is generated by scientists working together, has been highlighted to me (and continues to be emphasised to me) by a number of significant individuals.

Unfortunately we lost one of these individuals this year - Prof. Alan MacDiarmid. Alan passed away in February 2007. He was the Chair of our International Advisory Board, a scientific colleague and an inspirational individual.

Thanks Alan – the enthusiasm and collegiality you inspired in us will endure within ACES.

I am of course extremely proud of the accomplishments of individuals within ACES during 2007. You will see these accomplishments and the recognition they have generated spelt out in the following pages. ACES provides an excellent opportunity for our researchers to create and sustain a personal and team research portfolio that will further enhance Australia's scientific research credentials.

ACES is a significant national resource and I am excited about the prospects for 2008!

Best Wishes,

Gordon

From the International Advisory Board

The International Advisory Board reviewed the 2007 progress of the ARC Centre of Excellence for Electromaterials Science (ACES) on 20th February 2008. Those in attendance were: Dr Bridget Ogilvie (Chair), Prof Ray Baughman, Prof Siegmar Roth, Prof Andrew Holmes, Prof Richard Kaner, Prof Naoya Ogata and Dr Ian Sare. The Board was unanimously impressed by the quality and quantity of outcomes achieved by the Centre. The key outcomes for the year are summarized below.

HIGHLIGHTS OF PROGRAMS

PROGRAM 1: ELECTROMATERIALS

New Building Blocks - A wide variety of materials continues to be supplied from the **P1** program. New materials of note include a porphyrin dimer, a new thiophene-fullerene derivative, and thiophene monomers.

Nanodispersions – Biomolecules continue to be used as dispersants. Nanodispersions of defined rheology and surface tension have been produced that facilitate wetspinning of fibres with unique and elegant structures, or can be used in inkjet printing of functional structures.

Nanostructured Carbon Electrodes – Flexible robust electrodes based on aligned carbon nanotubes (ACNTs) have been produced.

Functional Electrolytes – A novel polymer electrolyte containing silica nanoparticles grafted with iodide salts has been developed, as well as novel plastic crystalline materials and nanocomposite electrolytes.

Modelling – Ab-initio structure calculations have been developed to understand electrochemical processes in ionic liquids.

Characterisation of Materials – State-of-the-art AFM equipment has been purchased. Solid state NMR and Diffusion NMR techniques continue to be developed and applied to characterise electromaterials.

PROGRAM 2: ENERGY CONVERSION.

The focus of the Energy Conversion Program remains the development of (flexible) dye-sensitised solar cells (DSSCs) and of improved performance artificial muscles. The exploitation of novel nanostructured electrodes to enhance performance is of primary interest.

Plastic Solar Cells - A national benchmark of 8% efficiency has been developed for a titanium dioxide-based solar cell sensitized with the ruthenium dye N719. This is comparable to or better than results from other leading international laboratories.

Electromechanical Actuators - First discovery that Inherently Conducting Polymer (ICP) actuators can operate in reverse to produce a mechanical sensor. First ever production of DNA/single-wall carbon nanotube (SWNT) fibres and their use as electromechanical actuators. Novel hydrogel/polyaniline/SWNT material has been developed that shows “dual-mode” actuation by responding to both electrochemical stimuli and pH changes. The highest ever actuation using polythiophene has been demonstrated using a novel solution-processable material developed in Program P1.

PROGRAM 3: ENERGY STORAGE

Lithium Battery Materials - SnSb carbon nanotube nanocomposites have been prepared and tested; these show high reversible capacity and excellent stability to > 50 cycles. At 480 mAh/g, their reversible capacity significantly exceeds the typical 320 mAh/g achieved with traditional graphite lithium-ion anode materials. A carbon nanotube-poly(methylthiophene) composite cathode has been developed that provides a reversible capacity as high as 90 – 100 mAh/g with good stability in an ionic liquid electrolyte; the key outcome here is the stability with this type of electrolyte.

Magnesium Batteries - A biocompatible primary cell has been developed based on a Mg anode, a low water activity ionic liquid electrolyte and a PEDOT/oxygen cathode. However, further development of this has shown that it can operate also as an air electrode of the type that is of major worldwide interest in fuel cells and metal/air batteries. The significance of the electrodes developed here is that they do not require Pt to catalyse the oxygen reduction reaction. Australian Provisional Patents have been filed.

Polymer Batteries and Capacitors - A polyaniline/CNT symmetrical capacitor has shown good capacity and cyclability.

PROGRAM 4: BIONICS

The release of the neurotrophin NT3 by electrical stimulation has been shown to promote neuronal outgrowth from primary spiral ganglia explants *in vitro.* The mechanism for NT3 attachment to and release from polypyrrole has been investigated using molecular modeling methodologies. Fasciculated growth of neurites on polymer fibres has been demonstrated. Electrode structures suitable for investigations that separate the effect of direct electrical stimulation from those encountered by controlled release of growth factor have been produced.

PROGRAM 5. ETHICS

The Education Program conducted a workshop in Wollongong on the ethics of risk and regulation in nanotechnology. Over 40 people attended the one day event with half the participants being members of the Centre of Excellence, in particular post-graduate students and early career researchers.

EDUCATION AND TRAINING

The main thrust of this activity was directed at PhD training of 34 students. Apart from the workshop on Ethics, there were also other workshops and short courses, for example in the area of characterisation of nano-materials. These courses were aimed at postgraduate students and early career researchers, but were also open to external interested parties. At the Wollongong node, there was further integration of Centre activities with the B. Nanotechnology course, and progress towards establishing an educational exhibition with the Wollongong Science Centre in the area of Electromaterials. Six PhD students graduated in 2007.

INTERNATIONAL PROFILE

Perhaps the greatest and certainly most exciting testimony to the Centre's international credentials is the ability to attract the highest calibre research students and research fellows from around the world. During 2007, 14 new PhD students were enrolled, with countries of origin including Australia, New Zealand, United Kingdom, France, Russia, USA, Spain, Germany, Thailand, Pakistan and China. High calibre students from world renowned research institutes were attracted to ACES. In addition, ACES hosted 37 international visitors from countries including the USA, UK, Japan, Korea, China, Ireland, Hong Kong, Switzerland and Singapore.

ACES personnel were invited to visit leading international laboratories on 32 occasions in 2007, including countries such as France, USA, UK, Sweden, Netherlands, Switzerland, China, Japan, Ukraine, Ireland and India.

There were 31 invited presentations at international conferences held in countries such as New Zealand, USA, Iran, Korea, Malaysia, China, Singapore, UK, Japan, Germany, Ireland and India.

OUTREACH

These activities include the Wollongong Science Centre Forum, Australian Innovation Festival and the Illawarra Innovation Showcase, Pacific Forum on Energy Options, Energy Futures Network, St Vincent's Hospital Neuroscience Research Retreat, and the University of Wollongong Professorial Lecture Series. ACES also attracted 44 media reports, not only from within Australia but also from overseas such as the UK (BBC), and USA (Fox 29, KENS 5, NBC).

KEY PERFORMANCE MEASURES

The performance of the Centre has substantially exceeded the 2007 targets. In particular, there were 72 refereed publications of which 51 had an impact factor greater than 2, 14 postgraduate students recruited, 6 postgraduate completions, 3 national/international workshops, 31 invitations to international conferences, 32 visits to leading international laboratories, 44 media reports, 3 patents lodged, 37 international visitors, and 7 new organisations recruited to collaborate with the Centre.

BENCHMARKING ACES IN AN INTERNATIONAL CONTEXT

The Chair, Dr Bridget Ogilvie, invited the IAB members to comment on where ACES stands in the international scene. The comments were as follows:-

Prof Ray Baughman (Director of the Alan G. MacDiarmid NanoTech Institute at the University of Texas in Dallas): "It is clear that what has been done emphasises that Australia is a technology leader. ACES is attracting the best people from around the world. ACES people are productive resulting in high impact publications". In fact "ACES is a national treasure".

Prof Siegmar Roth (Max Planck Institute for Solid State Research): "ACES has identified key research opportunities, areas where companies are investing; for example solar cells, batteries, fuel cells and Bionics. ACES characterisation facilities are internationally significant". He also added that ACES has the best young researchers in the world to provide the expertise to carry out and interpret the experimental data from this equipment.

Prof Andrew Holmes congratulated ACES on the quality and number of publications. He also noted that ACES work on Bionics was impressive and this was supported by Dr Bridget Ogilvie: "The Bionics program is clearly outstanding".

END-USERS

All IAB members agreed that ACES had established a highly regarded international reputation. It was also agreed that ACES can continue to capitalise on this reputation to attract the highest calibre research students and research fellows to Australia and to build strong, comprehensive collaborative research and commercialisation ventures across the globe.

The IAB considered the report provided by the End-Users group. It was agreed that ACES interfaced effectively with End-Users throughout 2007 (first year of operation of the End-Users Group). It was also agreed that some opportunities will go untapped without appropriate resources being dedicated to this task. ACES is a collection of mature, innovative, determined researchers. Effective commercialisation / translation of research will require a team of business development individuals with equal talent and drive working alongside these researchers.

The IAB also noted that ACES End-Users go beyond the traditional Industry Sectors represented within the current committee. ACES supplies valuable input into the training of individuals who move on to a wide range of sectors including government, research, teaching and administrative positions. ACES also works effectively with the Science Centre and the general community raising awareness of Science and technology through this exciting research venture. ACES also provides a first port of call for small business seeking advice or needing to know the state-of-the-art in the field of Electromaterials Science.

FINAL COMMENTS FROM THE CHAIR

"Congratulations on the 2007 achievements"

Dr Bridget Ogilvie AC, DBE, FRS, FMedSci
Chair
International Advisory Board for ACES

Highlights of the Core Funded Activities

In 2007 our research activities have led to exciting developments in all research program areas. The research outputs and further integration of the team at a number of levels are reflected in our publication list. Therein you will find 72 publications in total. In 30 of those, the authors are from more than one institution and of these some 14 involve international collaborators.

Highlights for 2007 are described here and a complete Milestones Report is available at Appendix I.

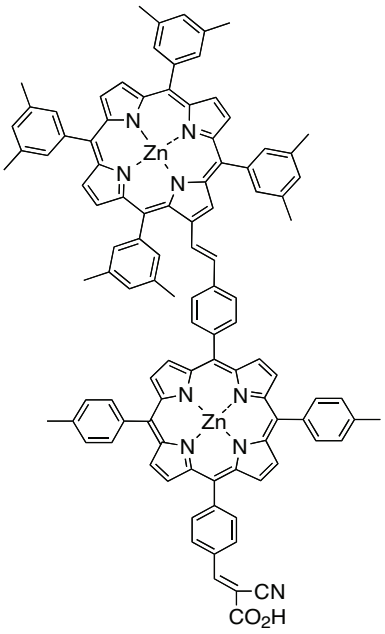
PROGRAM 1 (P1): ELECTROMATERIALS

As anticipated when we embarked on this research program, 2007 has been a year during which the strengths and some limitations of our existing electromaterials have been identified. The strengths have enabled us to charge forward on a number of fronts in energy storage, energy conversion and bionics and the supply of appropriate materials to these areas is ongoing. The limitations identified in the materials produced to date provide both challenges and new opportunities for the Electromaterials research team.

An exciting development involves the production of new material structures using simple approaches such as wet-spinning of fibres or inkjet printing. Access to these fabrication protocols has been made possible by our ability to produce stable nanodispersions of electrofunctional materials. While the exploration of nanostructures has revealed some amazing new physical properties in our materials of interest, it is the ability to process materials that are inherently non-processable that is having the most immediate impact.

NEW BUILDING BLOCKS

Supply of materials from **P1** to other programs is ongoing. These include, functionalised porphyrins, nanotubes, thiophenes and polythiophenes for solar cells, actuators, batteries and bionics applications. New materials of note that have been developed this year include the porphyrin dimer **1**, which is of particular significance for dye-sensitised solar cells, a new thiophene-fullerene derivative **2** that has the potential to provide electrochemically stable electroactive polymers, and thiophene monomers of the type **3** that can be used to produce processable polythiophenes.



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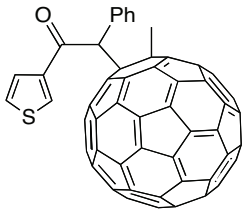

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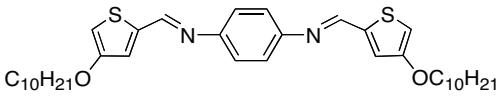

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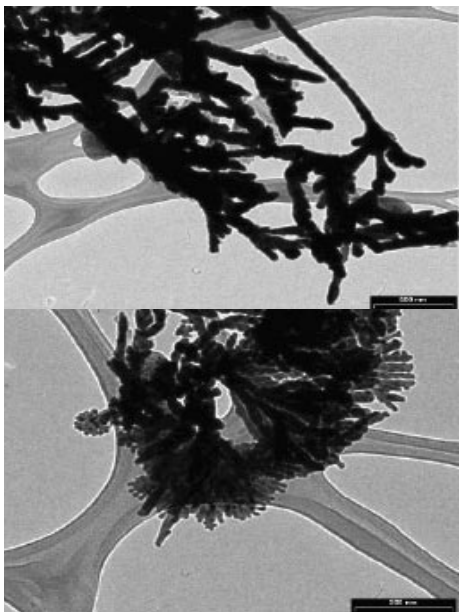


Figure 1. PPy nanostructure obtained through synthesis in an IL/H_2O biphasic system.

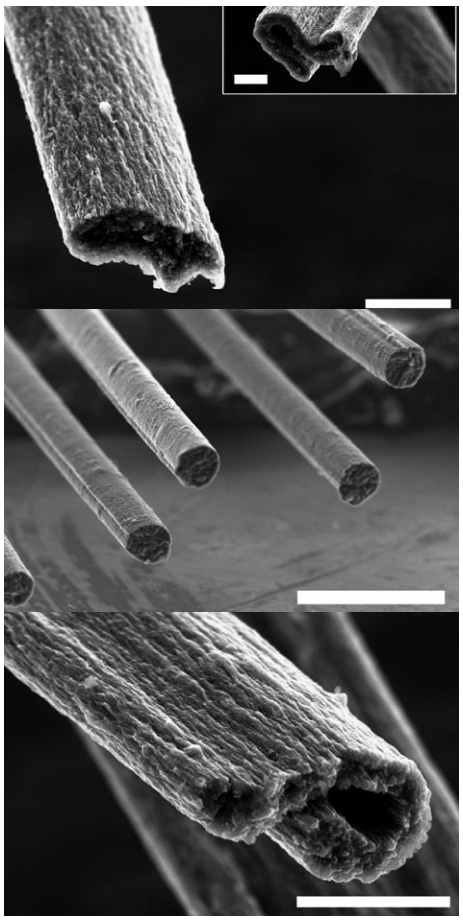


Figure 2. CNT fibres using a coagulant-free spinning process.

NANODISPERSIONS

The use of biomolecules as dispersants for electroactive materials received further attention during 2007. The synthetic biomaterial poly(styrene-ß-isobutylene-ß-styrene) (SIBs) – a material used to coat medical stents – has proven to be a highly effective dispersant for CNTs. Cast films (**Carbon 2004**) or electrospun nanotubes (**Chem. Mat. 2007**) produced from these dispersions were shown to have excellent mechanical and electrical properties and supported the growth of L929 fibroblast cells. Free standing nanoporous papers prepared from nanodispersions produced using biomolecules (DNA or chitosan) were also found to have excellent mechanical and electrical properties and again supported cell growth (**J. Biomed. Mat. 2007**). The ability to prepare stable nanodispersions containing TiO_2 and carbon nanotubes provided a route to novel composite electrodes useful in the photocatalytic oxidation of methanol (**J. Electrochem. Soc. 2007**).

In the pursuit of novel conducting polymer dispersions, procedures that enable incorporation of functional (dye) molecules have been developed (**React. and Funct. Polymers 2007**), as have synthesis protocols in ionic liquids (ILs) that enable the production of extremely high surface area (fractal) structures (**Macromolecules 2007**) **– see Figure 1.**

NANODISPERSIONS AND MATERIAL PROCESSING

The ability to create nanodispersions of defined rheology and surface tension has enabled simple processing options to be utilized to provide unique and elegant structures. Using CNT-biomolecule dispersions, the wetspinning approach has been further improved to allow the use of either a complementary biomolecule (**Adv. Mat. 2007**) or even a coagulant-free bath (**Adv. Funct. Mat. 2007**) to form long lengths of fibres (**see Figure 2**) with excellent mechanical and electrical properties. These fibres have been shown to be non-cytotoxic.

Our installation of custom-built wetspinning facilities has enabled fibre production at speeds of up to 8 m/min. Polypyrrole dispersions achieved using appropriate dopants have been used to enable wetspinning of polypyrrole fibres for the first time (**Synth. Met. 2007**).

The use of inkjet printing to produce functional structures has taken great strides forward in 2007. We have created unique electrochemical structures through inkjet printing polyaniline (**Langmuir 2007**) or carbon nanotube dispersions (**J. Mat. Chem. 2007**). Utilizing these structures as chemical/biosensors or as electrochromic materials has been explored.

NANOSTRUCTURED CARBON ELECTRODES

Protocols have been developed that enable flexible robust electrodes based on aligned carbon nanotubes to be produced (**Chem. Mat. 2007 – Provisional Patent Lodged**). These structures have been shown to provide excellent performance as electrodes used in Li batteries in research Program 3 – Energy Storage. Studies into their use as advanced cochlear implant electrodes have been initiated.

In addition, a novel approach that enables robust carbon nanoweb electrodes **(see Figure 3)** to be produced has been developed. This enables direct fabrication of high surface area carbon nanostructures that out-perform the aligned carbon nanotube structures in battery and capacitor applications. The use of these structures in the bionics program is also under investigation.

FUNCTIONAL ELECTROLYTES

We have developed a novel polymer electrolyte containing silica nanoparticles grafted with iodide salts. This has allowed fabrication of all-solid-state monolithic dye sensitised solar cells (DSSC) (**Adv. Funct. Mat. 2007**).

Functionalised silica nanoparticles incorporated as lithium ion salts in gel electrolytes have been used to produce gel electrolytes with efficient Li cycling for Li ion batteries **(Electrochimica Acta 2007)**.

Novel plastic crystalline materials (**Solid State Ionics 2007, Aust. J. Chem. 2007 and Electrochem. Comm. 2007**) and nanocomposite electrolytes based on them have been developed, with enhanced plasticity and ion transport being induced by the introduction of inorganic nanoparticles **(J. Phys. Chem. 2007).** These materials have superior mechanical properties, even above their melting point, and are therefore good candidates for all-solid state lithium batteries or DSSCs.

MODELLING

The integration of spectroscopic techniques such as Raman and NMR with theory (in the form of ab-initio structure calculations) has been used to develop an understanding of electrochemical processes in ionic liquids and how these impact on applications, including electrowinning of metals such as aluminium as well as lithium ion transport in battery applications (**Australian Journal of Chemistry 2007).**

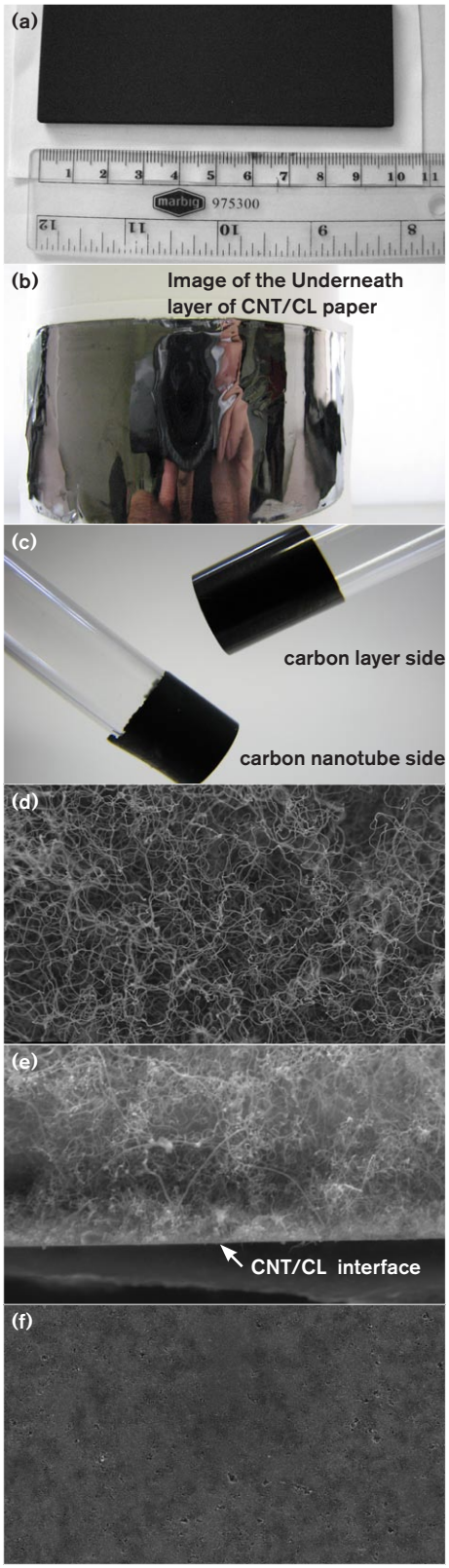


Figure 3. Scanning Electron Micrograph (SEM) and optical images of free standing CNT/Carbon Layer paper: (a) digital image of the upper surface of the CNT/CL, after CVD growth on a 40 cm^2 quartz plate; (b) digital image of the underneath surface of the CL layer when removed from the substrate, the reflectivity of the layer is visible from the reflected image of the photographer easily observed in the image; (c) digital image of CNT/CL paper removed from the quartz substrate and rolled onto glass rods, indicating the flexibility and mechanical robustness of both sides of the CNT/CL composite paper; (d) SEM image of the top surface of the film, showing a dense entanglement of carbon nanotubes; (e) SEM image of the cross section of the CNT/CL paper, showing an obvious 'intersection' between the CL layer (indicated by the white arrow) and the upper carbon nanotube network layer; and (f) SEM image of the underneath of the CL layer, showing densely packed but still porous morphology.

CHARACTERISATION OF MATERIALS

The acquisition of significant new characterization facilities in the area of Atomic Force Microscopy (AFM) will help cement our place as leaders in electromaterials research. Two state-of-the-art AFM systems have been acquired. The Asylum MFP-3D™ AFM system is capable of nanometre resolution imaging of biocomposites/ electromaterials in both ambient and liquid environments. The instrument can also perform ultra-low noise force measurements (< 100 piconewtons) to characterize local material properties. A second system, the JPK Nanowizard®II BioAFM, is specially designed to operate with a Nikon TE2000-U Inverted Microscope. This unique setup combines high resolution AFM and optical measurements (e.g. fluorescence microscopy) for advanced characterization of living cells. Both AFM systems also have *in situ* electrochemical capabilities **(see Figure 4)** and will be invaluable tools, especially in bionics, for understanding the effect of electrical stimulation on electrobiomaterials/single living cells.

Solid State NMR and Diffusion NMR techniques continue to be developed and applied to characterize electromaterials. We have developed a robust method for measuring diffusion coefficients in low fluidity, conductive materials (**J. Phys. Chem. 2007**). Key collaborations have also been developed to allow us to probe the dielectric response of electrolyte materials (**Aust. J. Chem. 2007**).

Significant improvements in solar cell characterisation have been made possible via our collaboration with the CRC Polymers. A solar simulator has been installed as well as facilities for transient absorption spectroscopy providing detailed insights into solar cell performance.

The Electromaterials Program has supplied tailor made polythiophenes and porphyrins to a number of projects within the energy storage, energy conversion and bionics programs as detailed below.

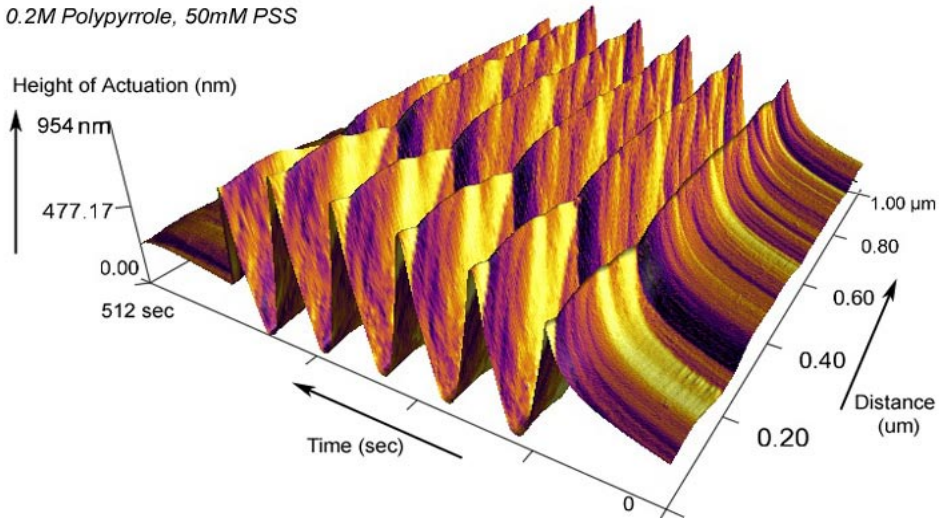


Figure 4. AFM 3-D image showing real-time nanoactuation of an organic conducting polymer film.

PROGRAM 2: ENERGY CONVERSION

The focus of the Energy Conversion Program remains the development of (flexible) dye-sensitised solar cells (DSSCs) and improved performance artificial muscles. The exploitation of novel nanostuctured electrodes to enhance performance in these areas is of primary interest.

PLASTIC SOLAR CELLS

The key task in the development of DSSCs within the Centre has been the creation of internationally competitive solar cell fabrication and characterisation facilities at both Monash and UoW. In 2007, we have developed a national benchmark of 8% efficiency for a titanium dioxide-based solar cell sensitized with the ruthenium dye N719. This is comparable to or better than results from other leading international laboratories.

We have continued to make significant progress in the development of each of the individual components of the dye-sensitised solar cell, both in the Centre laboratories as well as with our international collaborators. The highlights are as follows:

- World record 7% efficient porphyrin-sensitised liquid-junction DSSC. **(J. Phys. Chem. C 2007).**
- World record 4.2% efficient porphyrin-sensitised heterojunction solid state DSSC. **(J. Phys. Chem. C., 2008, submitted) – see Figure 5.**
- Novel synthetic methods developed for near-infrared absorbing cyanine and squarine dyes.
- Vacuum-based fabrication method developed increasing the conversion-efficiency of poly (ethylene-oxide) based polymer DSSCs from 1.33 to 3.54%.
- Development of new fabrication methods for mesoporous NiO film formation for tandem solar cells. Reported the highest current for dye-sensitized NiO solar cells.

A highlight of the year was the recognition of the work on dye-sensitised solar cells by ACES researchers with the award of a $6 million grant by the Victorian Government for the development of flexible solid state solar cells. This new research program will in-part build on developments that have been made in this ACES program and is reflected in the revised Program milestones.

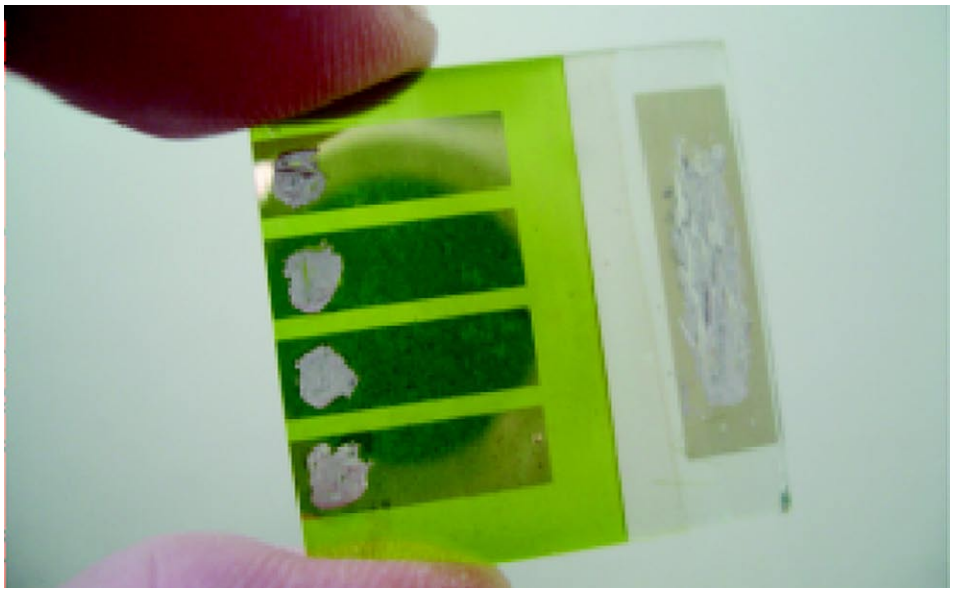


Figure 5. Example of green porphyrin-sensitised heterojunction solid state DSSC.

ELECTROMECHANICAL ACTUATORS

The Centre aims to advance the technology of electromechanical actuators by developing novel nano-structured electromaterials. Our ultimate goal is to produce a low-voltage actuator that can produce the same combination of movement, force and speed as generated by natural muscle. To achieve this goal, Centre researchers have been investigating the fundamental mechanisms of actuation that occur in conducting polymers, hydrogels and carbon nanotube composite materials. In addition, we have been developing operational models that predict the actuation output for a given input, eg. applied voltage.

The past year has seen the publication of several important papers that demonstrate significant breakthroughs achieved by Centre staff and collaborators:

- The highest ever actuation using polythiophene demonstrated using a novel solution-processable material developed in Program P1 **(Electrochimica Acta – 2007).**
- First discovery that ICP actuators can operate in reverse to produce a mechanical sensor. We proposed a mechanism for the sensor output and quantitatively estimated the magnitude of the voltage and current produced **(Advanced Functional Materials – 2007)**.
- First ever production of DNA/single-wall nanotube (SWNT) fibres and their use as electromechanical actuators **(Advanced Materials – 2007).**
- Novel hydrogel/polyaniline/SWNT material developed that shows "dual-mode" actuation by responding to both electrochemical stimuli and pH changes **(Sensors & Actuators B – 2007).**
- Continued development of working models of bender type actuators **(Materials Science & Engineering C; IEEE Transactions on Control Systems Technology - 2007)** and their use as a robotic fish propulsor **(Bioinspiration and Biomimetics - 2007) (Figure 6).**

We continue to develop a better understanding of the complex processes occurring from the molecular to the macroscopic scale that determine the performance of artificial muscles. This improved understanding allows us to engineer the structure of the materials at the nanoscale so as to improve their performance as actuators.

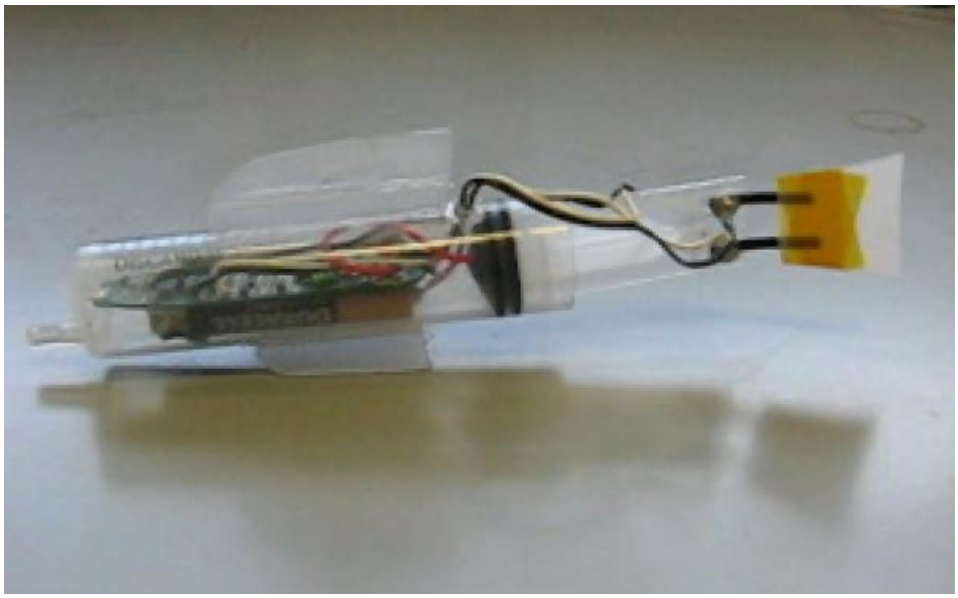


Figure 6. The robotic fish being developed in collaboration with DSTO.

PROGRAM 3: ENERGY STORAGE

The use of novel nanostuctured electromaterials to enhance the performance of energy storage devices, with a view to developing flexible, wearable or printable structures, remains our strategic goal.

LITHIUM BATTERY MATERIALS

In 2007 the program was active in all aspects of materials for lithium and lithium-ion cells. The emphasis in this work is on materials that can be used in preparing a thin film cell, potentially using inkjet printing technology.

In the anodes area, tin based materials have been intensively investigated and several alternatives developed **(Angewandte Chemie - 2007)**. SnSb carbon nanotube nanocomposites have been prepared and tested **(Chemistry of Materials -2007)**; these show high reversible capacity and excellent stability to > 50 cycles. The 480 mAh/g reversible capacity significantly exceeds the typical 320 mAh/g achieved with traditional graphite lithium-ion anode materials. Solid polymer electrolyte materials have also been developed which will allow the printing of a multi-layer device **(J. Power Sources - 2007).** These are based on blends of polymer components (either polyethylene-oxide or polyvinylideneflouride based) with an ionic liquid. The latter provides a plasticising effect to enhance conductivity without introducing a volatile component to the electrolyte. The electrolytes are able to form free-standing films.

A number of cathode materials have been investigated **(J. Power Sources - 2007)**. A problem identified in this area in 2006 related to unstable cycling behaviour that needed to be resolved to allow the use of ionic liquid components in the electrolyte (because of their high conductivity and low volatility). A carbon nanotube poly(methylthiophene) composite has now been developed which provides a solution to this problem and provides a cathode material that can be of use in lithium cells as well as other battery types. The composites approach allows a synergistic combination of the high conductivity of the carbon nanotubes (which form a conductive matrix for the materials) with a high capacity material that is deposited onto the nanotubes. Reversible capacity as high as 90 – 100 mAh/g is obtained with good stability in an ionic liquid electrolyte; the key outcome here is the stability with this type of electrolyte **(J. Electrochem. Soc. - 2007).**

POLYMER BATTERIES AND CAPACITORS

A number of polymer battery structures have been produced. The best performance obtained to date involves the use of a polypyrrole cathode and a functionalized polythiophene anode to produce a discharge capacity of 39.1 mAh/g. Similarly polymer capacitor structures utilising nanostructured polyaniline – carbon nanotube electrodes have been constructed (**Figure 7**). Capacitance values of 500-600 F/g have been obtained (**J. Power Sources – 2007**).

MAGNESIUM BATTERIES AND A NOVEL PT FREE AIR CATHODE

Within the Advanced Metal Battery program, attention has focussed on batteries that can be used in the context of bionic devices, these being biocompatible and preferably bioabsorbable. Magnesium based cells show great promise in this context and are of interest also in a broader range of applications **(Aust. Prov. Patent App. March 2007**).

A biocompatible primary cell has been developed based on a Mg anode, a low water activity ionic liquid electrolyte and a PEDOT/oxygen cathode. The PEDOT/oxygen cathode was designed to operate on the basis of dissolved oxygen in the aqueous environment. However, further development of this has shown that it can operate also as an air electrode of the type that is of major worldwide interest in fuel cells and metal/air batteries (**Aust. Prov. Patent Application December 2007**). The significance of the electrodes developed here is that they do not require Pt to catalyse the oxygen reduction reaction.

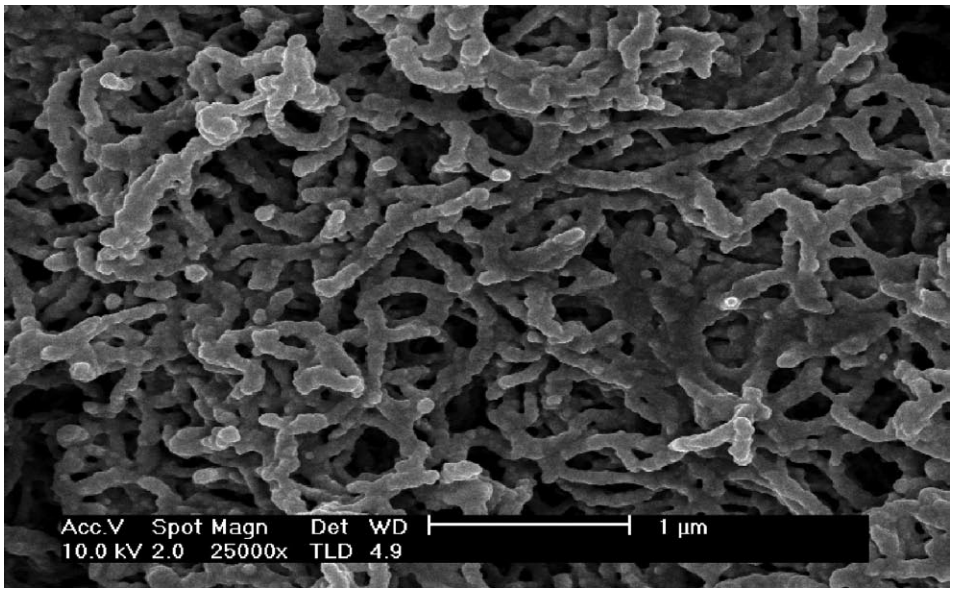


Figure 7. SEM of CNT-Polyaniline super capacitor electrode.

PROGRAM 4: BIONICS

The Bionics program aims to elucidate the factors that facilitate the transfer of electrical energy between organic conductors and the body and in particular the nerves. This research is being directed towards a new generation of cochlear implants for deafness and spinal cord scaffolds to provide a functional link across a damaged section of the cord.

CELL INTERACTION STUDIES

Investigation of Inherently Conducting Polymer (ICP)/cellular interactions indicate that interfacial chemistries promote variations in the growth of primary neuronal structures (Dorsal Root Ganglia).

Variations in the interfacial chemistry were introduced by simply altering the molecular dopant used in the conducting polymer polypyrrole.

ELECTRICALLY STIMULATED PROMOTION OF NEUROREGENERATIVE ACTIVITY FROM ICPS

Fundamental knowledge has been gained on how the energy transfer properties of ICPs can be used to promote a pro-neurogenic environment. Electrical stimulation has been used to effectively release the neurotrophins NT3 and BDNF from polypyrrole.

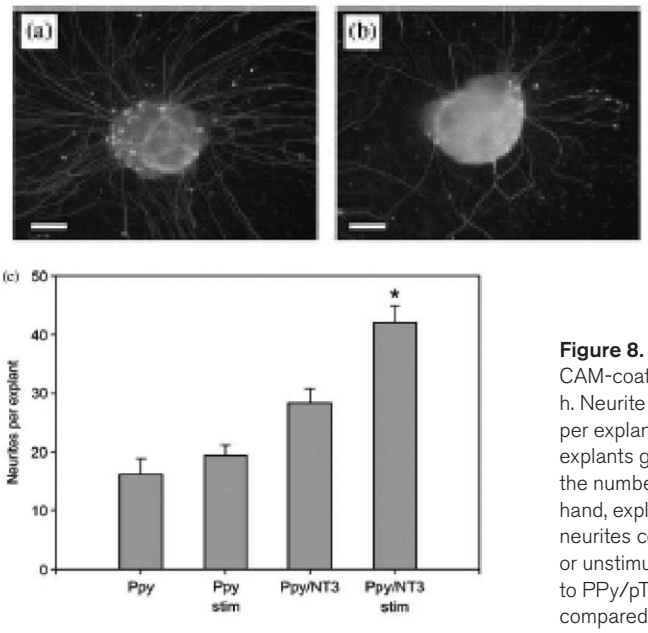


Figure 8. Electrical stimulation of PPy for release of NT3. Explants were grown for 24 h on CAM-coated PPy/pTS or PPy/pTS/NT3 and subjected to a biphasic current pulse stimulus for 1 h. Neurite outgrowth was examined after a further 3 days in culture. A greater number of neurites per explant were observed on explants grown on the stimulated PPy/pTS/ NT3 (a) compared to explants grown on stimulated PPy/pTS (b). (c) Stimulation of PPy/pTS did not significantly alter the number of neurites per explant compared to unstimulated PPy/pTS ($p = 1.0$). On the other hand, explants grown on PPy/pTS/NT3 with applied stimulation had enhanced outgrowth of neurites compared to explants grown on unstimulated PPy/pTS/NT3 and compared to stimulated or unstimulated PPy/pTS ($p < 0.001$). Error bars represent standard error of the mean. PPy refers to PPy/pTS, 'stim' refers to 1 h stimulation and PPy/NT3 refers to PPy/pTS/NT3 ($p < 0:001$) compared to all other means. Scale bars are 100 mm (Richardson et al., 2007).

The release of NT3 by electrical stimulation has in turn been shown to promote neuronal outgrowth from primary spiral ganglia explants *in vitro* (**Biomaterials 2007**) **– see Figure 8** and a study has been conducted to evaluate the effect of electronically stimulated release of NT3 from polypyrrole in the cochlea of test animals.

In more recent work, the incorporation and electrically stimulated release of BDNF and BDNF/NT3 combinations from a single polymer have been investigated.

It is known that the neurotrophic effect of NT3 is enhanced when used in conjunction with BDNF, another neurotrophic protein. Thus the release of NT3 and BDNF together from polypyrrole was evaluated using radiolabelled proteins. It was found that both proteins could be released concurrently, although with slightly modified release kinetics.

The release of NT3 from a polymer containing both proteins was somewhat decreased compared to release of the single protein. Conversely, the release of BDNF was slightly enhanced in conjunction with NT3.

The biological effects of the release of both neurotrophins were determined using auditory nerve explants derived from the cochleae. The stimulated release of both neurotrophins was found to greatly enhance neurite outgrowth from the nerve tissue, indicating much greater survival and growth of the nerves in culture (**Figure 9**).

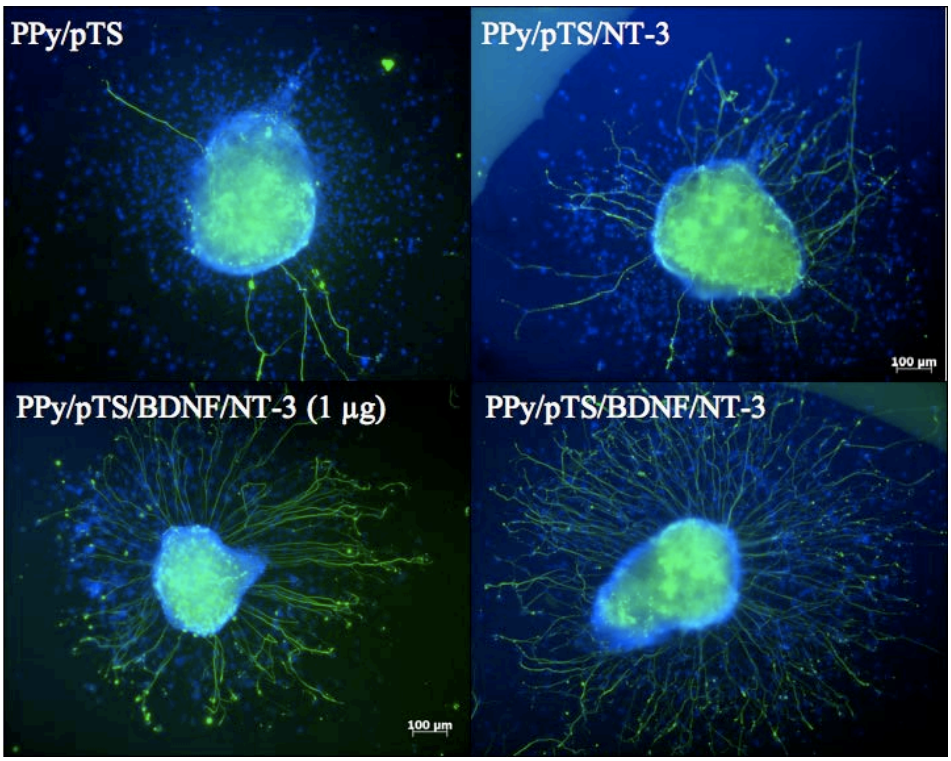


Figure 9. Images of auditory nerve explant growth on different polymers (only stimulated films shown).

MOLECULAR MODELLING OF NEUROTROPHIN (NT3)/POLYPYRROLE INTERACTION

The mechanism for neurotrophin (NT3) attachment to and release from polypyrrole has been investigated using molecular modelling technology. These studies have raised the possibility that mechanisms underlying incorporation and release of biomolecules from ICPs may involve complex interactions encompassing polar and/or non-polar interactions between the protein and polymer **(Figure 10).**

ADVANCED ELECTRODE DESIGN AND DEVELOPMENT

Electrode structures suitable for studies aimed at separating the effect of direct electrical stimulation from those encountered by controlled release of growth factor have been produced. In this design (**Figure 11**), cells are grown in two chambers on the slide and can be propagated between the electrodes to evaluate the effect of stimulated growth factor release, or on top of the electrodes to evaluate the effect of direct electrical stimulation on the cells.

The mylar composition of the chamber slide surface further facilitates evaluation of micro-structured and nano-structured polymer tracks (either wet-spun fibres or printed tracks) that can be located between or on top of the stimulation electrodes. This system allows assessment of multi-dimensional stimulation paradigm effects on any cell type using any fibre configuration.

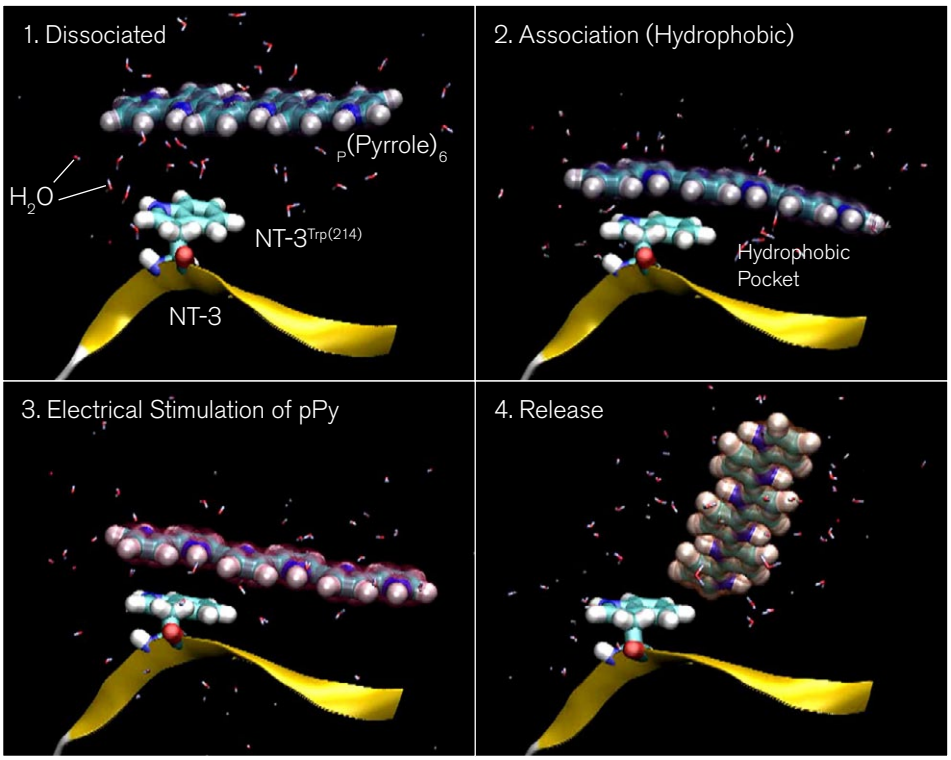


Figure 10. Molecular Model of NT3/PPy Interaction.

1. A small section of non-polar PPy (6-monomer units) is shown in a free aqueous environment dissociated from a section of the NT3 tertiary structure at the 214th amino acid (Tryptophan).

2. A hydrophobic interaction occurs between the Trp^{214} and PPy section, by way of a hydrophobic pocket.

3. Passage of electrons through the PPy carbon backbone via the application of an external electrical current leads to a breakdown of the hydrophobic interaction between the PPy and Trp^{214} by creating a stimulated polar environment between the NT3 and the PPy.

4. The breakdown of the hydrophobic pocket leads to the electrically stimulated dissociation of the NT3 and the PPy and release of the NT3 into the aqueous environment.

In parallel studies in Program 1 electrode structures based on aligned carbon nanotubes have been configured for use as an advanced Cochlear implant electrode. Carbon nanotubes (CNTs) present the possibility of delivering high density electrical stimulation in bionic devices such as the cochlear implant. Use of carbon nanotubes for implanted electrodes requires testing of the biocompatibility of the nanotubes within living tissue. Intensive studies have been initiated to evaluate the biocompatibility of CNTs within the body.

The development of high density CNT electrodes also requires the connection of CNTs with electronic devices to deliver electrical stimulation where it is needed. A masking system has been developed to address aligned CNTs to electrical (platinum) wiring and a new nanoweb format of nanotubes has been developed to increase the charge density of existing platinum electrodes. These systems are being explored using cochlear implants in animal models to generate new-generation high density electrode systems (**Figure 12**) for bionic implants.

PROGRAM 5: ETHICS

The ACES Ethics program has two distinct roles: critical analysis of the social, ethical and political implications of novel electromaterials and development of a research training program for students and researchers that includes an introduction to values clarification, ethical debate and responsible science. During 2007, a research fellow, Dr Renee Kyle, was appointed to the Ethics Program and has commenced research on medical bionics as well as contributing to the ethics education program.

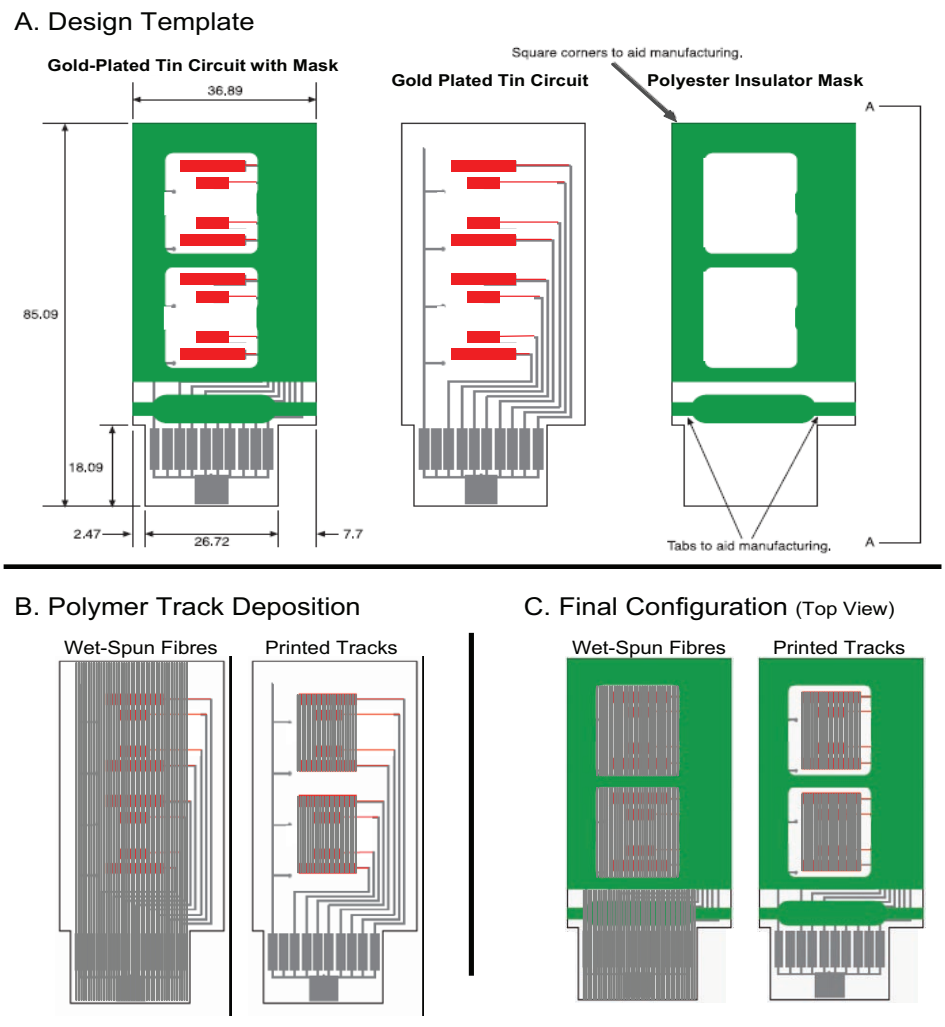


Figure 11. Schematic file drawings of twin chambered electrical cell culture chambers. The cell chambers consist of a mylar sheet with gold-plated tin circuitry printed on the configuration shown (A). Two large outer electrodes provide electrical stimulation points, while two smaller centrally located electrodes provide recording electrodes in each chamber. Wet-spun fibres or printed tracks of polymers can be added to the surface (B) and the chamber slide reconfigured (C) to evaluate the effect of electrical stimulation, growth factor release and micro-nano structure on the directed growth of nerve, muscle and endothelial cells within the system. This data can then be used for the construction of devices for implantation into mammalian tissues.

ETHICS EDUCATION PROGRAM

In 2007 the Education Program conducted a workshop in Wollongong on the ethics of risk and regulation in nanotechnology. The workshop was organised by Profs. Sue Dodds and William Price. Over 40 people attended the one day event with half the participants being members of the Centre of Excellence, in particular post-graduate students and early career researchers. Other attendees came from a variety of State and Federal agencies such as Workcover and NICNAS (The Australian Government regulator of industrial chemicals) as well as researchers from NSW and Victorian Universities.

There were three main speakers at the Workshop. Prof. Brian Priestly, Head, Australian Centre for Human Health Risk Assessment (ACHHRA) at Monash, who is a toxicologist experienced in research relating to the risks and toxicology of nano-sized materials, spoke on "*Nanotechnology: Health and Safety Issues from the Perspective of a Toxicologist*".

The second speaker was Dr. Karinne Ludlow from the Monash Centre for Regulatory Studies, who is an expert on regulation of nanotechnology. She recently played a central part in a recent Review undertaken for the Federal Government on the Impact of Nanotechnology on Australia's Regulatory Frameworks, along with Dr. Diana Bowman and Prof Graeme Hodge. Karinne's talk, *"Regulating Nanotechnology as if One Size Fits All?"*, linked the growing state of knowledge of the potential hazards of the materials to the current regulatory framework in Australia and compared it to other nations such as USA and Europe.

The third speaker, Prof. Susan Dodds, from the University of Wollongong, spoke on "*Ethics of Risk and Regulation in Nanotechnology".* There was a lively panel discussion after the formal papers.

Research highlights:

- R. Kyle. Nanotechnology: Changing Social Relations. Invited presentation at *The Governance of Science and Technology;* A Joint GovNet/CAPPE/ UNESCO Conference 9-10 August 2007, Australian National University.
- R. Kyle. Sounding out the self: Ethical implications of bionic devices. ACES Full Centre Workshop, Melbourne, St. Vincent's Institute for Medical Research; 3-4 October 2007.

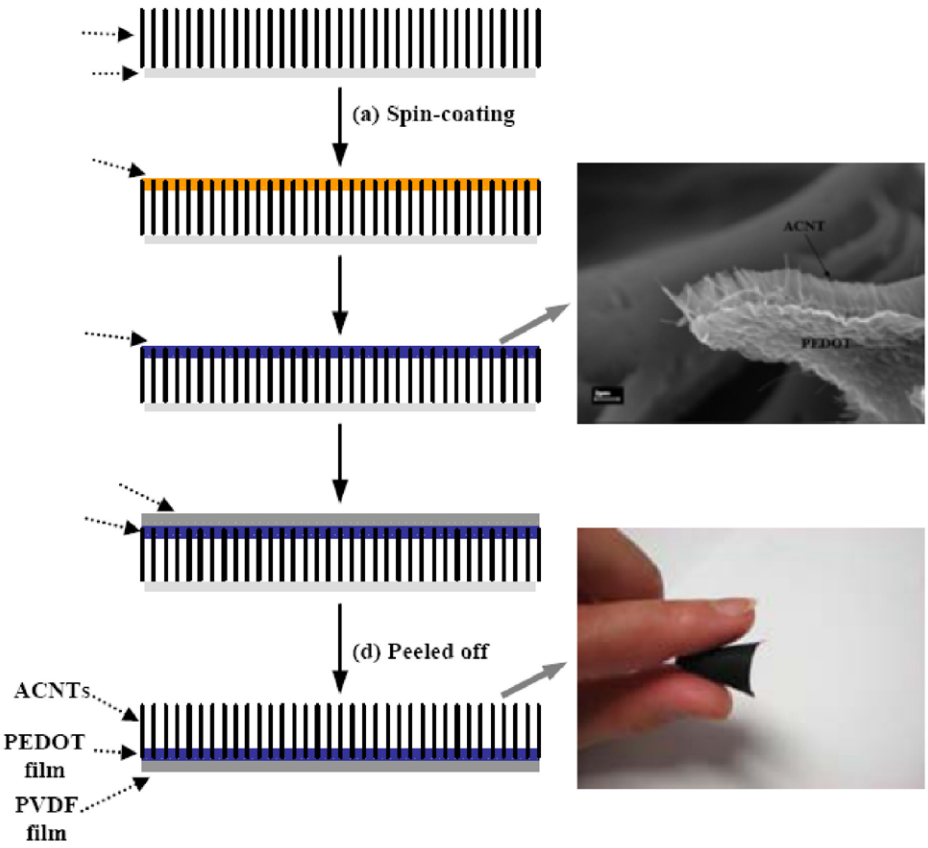


Figure 12. Process of Aligned Nanotube Electrode Surface Manufacture: Aligned CNTs are formed on a quartz surface and coated with a conducting polymer film (PEDOT) to facilitate conductivity through the CNTs. The conductive polymer surface is then coated with a further non-conductive polymer (PVDF) which confers a flexible property to the CNT/conductive surface and allows the structure to be peeled off the quartz substrate. The PVDF can be micro-patterned to generate individual address points for the aligned CNT conductive fibres.

Education and Training

The Education Committee reports directly to the Executive Committee and is composed of Prof. William Price (Chair – Chemistry, UoW), Prof. Geoff Spinks (Materials Engineering UoW), Prof. Yi-Bing Cheng (Materials Engineering, Monash), Kaylene Atkinson (IPRI, UoW), Dr. Peter Innis (IPRI, UoW) and Dr. Toni Campbell (IPRI, UoW).

In the second year of operation the Education Committee has continued its role to provide education and training for both members of the Centre and the broader community through a range of activities. The goals for 2007 were to continue the training programs for staff and research students in the area of ethics and regulation in Nanotechnology, further workshops in the area of characterisation of nano-materials, and a range of other specific training and education programs through seminar programs and short courses. Activities this year built on the successes of last year and broadened the range of training activities for post-graduate students and early career researchers. This year another focus was to offer the programs to external groups and interested parties. In addition, the events organised have brought together staff and students from different nodes of the Centre, thus facilitating cross-fertilisation of ideas and collaboration. Another highly successful related sphere of activity has been close integration of Centre activities at the Wollongong node with the Nanotechnology undergraduate degree.

In addition, significant progress has been made towards the establishment of an educational exhibition in the area of Electromaterials and their impact on society in collaboration with community based Science Centres. This represents part completion of a Year 3 milestone.

Specifically, during 2007 the following major events have been organised and successfully run:

WORKSHOPS/ SHORT COURSES:

- Short Course on Advanced Electrochemical Techniques for students and early career researchers (Wollongong Feb 2007).
- Workshop on Synthesis and characterisation of Carbon Nanotubes (Wollongong March 2007).
- Workshop on Characterisation of Electromaterials by Electrochemical Mapping Raman (July 2007 Wollongong).
- Workshop on Electrochemical techniques in Corrosion Research (Monash Aug 2007).
- Workshop on NMR techniques (Monash September 2007).
- Post-graduate and Research Fellow in–house workshops (ACES Centre Meetings Feb 2007 Wollongong and October 2007 Melbourne).
- Workshop on Ethics of Risk and Regulation in Nanotechnology (Nov 2007 Wollongong).
- Workshop on Ink-Jet Printing of Functional Materials (Wollongong Dec 2007).

Full reports on most of these events are to be found on the ACES website: (**http://www.electromaterials.edu.au/Resources/conferencereports2007.html#centremeet**). A summary and excerpts of some of the activities carried out are given below.

Both **ACES Centre Meetings** (in February in Wollongong and in October at St. Vincent's Hospital, Melbourne) featured educational workshops for students and early career researchers. In particular, the February Centre Workshop included a full day short course on Advanced Electrochemical Techniques. This was attended by 30 students and research workers. The speakers were Prof. Dennis Tallman (University of North Dakota, USA), Prof. Frank Walsh (University of Southampton, UK) and Dr. Peter Innis (UoW). These speakers presented advanced insights on the material requirements of a range of electrochemical techniques and the role nanotechnology has to play.

A **carbon nanotube (CNT) workshop** for both ACES members and external parties was organised on 15-16th March 2007. CNTs have attracted increasing attention from materials scientists and engineers over the past decade. Their potential for use in organic electronics or as new electrode materials for capacitors and batteries and even in biomedical devices demonstrates the versatility of these amazing materials. The workshop was an opportunity to have an in-depth look into practical aspects governing CNT synthesis (Dr Andrew Minett & Dr Jun Chen), fabrication (Dr Marc in het Panhuis, Dr Philip Whitten & Dr Joselito Razal) and characterisation. Two highly important characterisation tools for CNTs: ESR and Raman spectroscopy were introduced (Assoc Prof Peter Innis). Professor Suzi Jarvis from Trinity College Dublin talked about the use of carbon nanotube probes associated with AFM techniques. Demonstrations were carried out on: the ATOMATE facility for producing multi-wall CNT systems (Dr Jun Chen and Dr Andrew Minett) as well as on structure assembly of fibres; gel spinning (Dr Joselito Razal), electrospinning (Dr Dan Li), and synthesis of bucky paper (Dr Philip Whitten).

The second **workshop on Ethical issues** surrounding the use of nanotechnology was held in November 2007 in Wollongong, being organised by Profs. Sue Dodds and William Price. This workshop was designed to start to come to grips with some of the issues surrounding risk and regulation and to reflect on the implications of this range of issues for the development of nanotechnology in Australia. Over 40 people attended the one day workshop with half the participants being members of the Centre of Excellence, in particular post-graduate students and early career researchers. Other attendees came from a variety of State and Federal agencies such as Workcover and NICNAS (The Australian Government regulator of industrial chemicals) as well as researchers from NSW and Victorian universities.

There were three main speakers at the Workshop: Prof. Brian Priestly, Head, Australian Centre for Human Health Risk Assessment (ACHHRA) at Monash; Dr. Karinne Ludlow, from the Monash Centre for Regulatory Studies, who is an expert in regulation of nanotechnology; and Prof. Sue Dodds, from University of Wollongong. They discussed issues of ethics as related to the health and environmental risks associated with nanomaterials. These sessions were followed by a panel led forum which again had excellent participation. The workshop was deemed to be highly successful and is likely to lead to another being organised next year.

A number of workshops have also been held at the Monash node of the Centre. Fifteen graduate students and researchers attended a one-day **workshop on Echem techniques in corrosion** in August 2007. Senior research students led the discussion in topics covering specimen and electrode preparation (metallography) to ensure accurate and reproducible results, linear polarisation resistance, cyclic potentiodynamic polarisation and microcapillary electrochemical measurements. Dr. Frederic Blin (from Maunsell), Dr. Nick Birbilis (CoE for Light Metals) and Dr. Patrick Howlett (ACES) shared their insights in modelling and interpreting EIS measurements. In addition, there was an in-house training **workshop on NMR techniques** in September for post-graduate students and early career researchers organised by Prof. Maria Forsyth. The focus was on solid-state NMR and diffusion measurements and featured significant hands-on training for the students.

INVOLVEMENT WITH UNDERGRADUATES

A significant part of the Centre's activities in education involves participation in the four year Nanotechnology degree at Wollongong. Students in the degree are involved in research projects and activities within ACES from their first year to enthuse and inform them about cutting edge science and research in this area. In 2007, Centre staff and chief investigators have been involved in teaching and supervision of Nanotechnology students, with some students carrying out third year projects within ACES. Four students were also awarded Summer Scholarships to work on Centre related projects. With the first cohort of graduating Honours students in Nanotechnology in 2007, three first class students are already committed to joining ACES as PhD students in 2008. This is testament to the success of the degree in educating high calibre students and attracting them into research and to ACES' significant educational role in this endeavour. In addition, ACES has offered three scholarships to Nanotechnology undergraduates in a competitive process to attend the forthcoming International Conference on Nanotechnology and Nanoscience in February 2008 in Melbourne (ICONN2008). This will be an outstanding opportunity for these students to broaden their knowledge of the area, and in particular to take part in the educational workshops planned.

SCHOOLS OUTREACH/ SCIENCE CENTRE ACTIVITIES

Other major outreach activities this year include a Victoria High School Science Teachers Professional Development Day in early December 2007. In this, ACES senior investigators, Profs. Maria Forsyth and Doug MacFarlane, conducted a session on Supplying and Using Energy to a group of 120 senior high school teachers as an update on material in the new VCE curriculum Units 3 and 4 (Year 12). This included a lecture from Professor MacFarlane producing details of laboratory experiments proposed for the students with an emphasis on simple and readily available equipment. This was much appreciated by the teachers. (Professor MacFarlane's lecture may be found on line at **www.electromaterials.edu.au**). Profs. MacFarlane and Forsyth also held an open discussion session on how ACES could support teachers delivering these topics in Year 12. The teachers were then hosted in small groups in the ACES labs to gain some hands-on experience with solar cells, fuel cells and batteries.

INTERNODE COMMUNICATION

Program meetings involving all nodes are held once per week on a rotational basis for P1-P2-P3-P4. Researchers from all sites (UoW, Monash, St Vincent's) participate in this weekly by phone-ins.

There have been active seminar programs at both Monash and Wollongong, with regular (one-per-week) external speakers on a wide range of topics for students and research workers, as well as internal seminar series at both nodes for students to present to their peers. This has also enabled visiting staff from Monash to present to Centre members at Wollongong and vice-versa, resulting in effective exchange of ideas and education.

ST VINCENT'S HOSPITAL ACES FULL IN-HOUSE WORKSHOP

The ACES Full Centre Workshop was held over the 3rd and 4th of October 2007 at the St Vincent's Hospital Melbourne (SVHM) Campus. The workshop was well attended, with some 55 participants from Monash University, University of Wollongong, the Bionic Ear Institute and St Vincent's Hospital.

The workshop was opened by ACES director, Prof Gordon Wallace, followed by an introductory exposition of Medical Bionics, as the primary theme of the SVHM program, from Bionics Program leader, Prof Graeme Clark. Appropriately, the scientific presentations were initiated by a presentation by Dr Renee Kyle on the ethics of nanobionics.

In a tightly packed program, 25 oral and 16 poster presentations, ranging in subject from conductive polymers' effects on cell growth and behaviour to development of new battery/greenpower and ionic liquid systems for integration into novel bio-physiological devices, were delivered over the two days. From a Bionics perspective, the presentations collectively emphasised the exciting integration of novel technologies throughout the ACES program and highlighted the tremendous potential of the ACES programs to deliver bionics solutions to medical issues.

All presentations were followed by intense and informative discussions that further brought home the convergence of the individual themes of the five ACES programs and laid the foundations for important cross-disciplinary understanding of scientific issues and principles and how these may be used to give rise to and explore new scientific frontiers.

These discussions carried through to dinner on the first night, where the cordial collegiality of the ACES researchers was most effectively demonstrated by a warm welcome speech from Prof Leon Kane-Maguire.

Graduate Training

Education and training have been mainly aimed at the PhD level. There were 33 PhD students enrolled during 2007 (Appendix II) of which 6 PhD students graduated.

UoW-IPRI PhD students Grace Stevenson with her poster (above) and Javad Foroughi (below) explaining his poster to other students in the centre.

International Profile

HIGHEST CALIBRE

Perhaps the greatest, and certainly the most exciting, testimony to our international credentials is our ability to attract the highest calibre research students and research fellows from around the world. During 2007, 14 new PhD students were enrolled, with countries of origin including Australia, New Zealand, United Kingdom, France, Russia, USA, Spain, Germany, Thailand, Pakistan and China.

ACES has also continued to build on important strategic alliances in a number of countries.

INTERNATIONAL CONSORTIUM IN ORGANIC SOLAR CELLS (ICOS)

In 2006, DEST awarded a $1.2 million International Science Linkages grant over 3 years (2007-2009) to the International Consortium in Organic Solar Cells led by Professor Andrew Holmes (University of Melbourne) and comprising Australia's leading organic solar cell researchers in 6 universities and the CSIRO, as well as researchers in 6 international institutions. Since two of those institutions, Monash University and the University of Wollongong are involved in the Centre, ACES solar cell researchers play a significant part in ICOS.

In this first year of ICOS, the ACES solar cell program (at both Monash and UoW) has already benefited significantly from researcher interaction in the ICOS program.

The "start-up" ICOS meeting was held in February, 2007, providing the Centre with significant publicity in this very high profile research area. ACES researchers at both Monash and Wollongong visited all the international partners and most of the national ICOS member institutions. This has enhanced the ongoing collaborations between ACES researchers and the other Australian partners and led to new collaborations between ACES researchers and IMRE (Singapore), Imperial College, Georgia Tech and Cornell.

Pictured at the first ICOS international consortium meeting at the University of Wollongong are (from left) Professor Gordon Wallace (UoW), Professor David Officer (UoW) and Professor Andrew Holmes (University of Melbourne)

AUSTRIA

ACES has become an international partner with a sister centre of **Electrochemical Science** in Austria. The Centre is located in Neustadt and is partnered with Universitat Wien, TU Wien, TU Graz and Universitat Innsbruck. Exchange of staff and students on parallel projects is planned in 2008-2010. Prof Gerhard Nauer is the Director of the Centre.

CHINA

ACES has developed significant linkages with Shanghai JiaTong University (SJTU). During 2007, a joint symposium hosted by our Chinese colleagues and led by the ACES Director (Prof Gordon Wallace) and Prof Ma, SJTU was held. A delegation from SJTU also visited the ACES Monash node.

The first UoW-SJTU bilateral symposium on The Application of Nano and Energy Materials was held at Shanghai Jiao Tong University (China) on 1st November 2007.

The purpose of this symposium was to enhance existing collaborative research and develop further projects between the two universities. The symposium's main focus was on the Synthesis of NanoMaterials and their application in bioelectronic, bionic, and electrochemical devices. Prof. Lee Astheimer, ProVice-Chancellor (Research) at UoW and other leading professors from the science and engineering faculties at UoW presented their innovative research.

Professor MacFarlane gave a Keynote lecture on Plastic Crystal Electrolytes and Professor Forsyth an invited lecture on NMR characterisation of solid state electrolytes at the Solid State Ionics 16 International Conference in Shanghai, July 2007.

This biennial meeting is the focal point of solid electrolyte research in the world. It is attended by 500 – 600 delegates.

Professor Forsyth is a Counsellor of the International Society of Solid State Ionics which is the governing body for the field.

Two other ACES researchers also presented talks at the meeting. The ACES team distinguished themselves at the conference banquet by presenting a fine rendition of Waltzing Matilda led by Professor Forsyth.

DENMARK

Research into the development of new conducting composites based on polyurethanes was accelerated by an extended visit from two PhD students, Mathilde Jakobsen and Anne Grydgaard from the **Technical University of Denmark**.

Through the support of the Australian Academy of Science, this collaboration will be extended in 2008, with Dr Jun Chen and Prof Wallace visiting Denmark.

Front row (from left): Prof. Mark Walker, Prof. David Officer, Prof. Shun-Ai Che, Prof. Shixue Dou, Prof. Zifeng Ma, Prof. Lee Astheimer, Prof. Gordon Wallace, Prof. Leon Kane-Maguire, and Prof. Nick Dixon. Behind the front row (from right): Dr Jun Chen, Associate Prof. Xianxia Yuan

FRANCE

In collaboration with Dr Philipe Poulin (**CNRS France**), further investigations into CNT-biomolecule dispersions were carried out. It was discovered that the formation of ordered CNT phases is indicated in the presence of the biomolecule. This work was carried out by Dr Moulton (ACES) during a visit to France and by Dr Lucie Viry during a visit to ACES - UoW in Australia.

DR SIMON MOULTON VISIT TO CNRS FRANCE: DR PHILIPPE POULIN

Simon visited Dr Poulin's laboratory for 2 weeks to continue work on the phase properties of carbon nanotubes dispersed in biological solutions. The work focussed on the self assembly of carbon nanotube-biomolecule formulations into ordered phases. This collaborative work was published in the Journal of the American Chemical Society (JACS 129, 9452-9457, 2007).

Mr Matthieu Gabet and Laure Delavernhe from University Nantes spent a three month period at Monash investigating various surface preparation characterisation techniques (including electropolishing and profilometry) for magnesium and magnesium alloys.

GERMANY

A number of research interns were hosted from German Universities at ACES-Monash.

INDIA

ACES-Monash is developing links with both DSIR Chennai and IIT Bombay in the use of ionic materials in biosensors.

Other valuable links with India were made by Prof. Leon Kane-Maguire when he attended the Indo-Australia Symposium on Multifunctional Nanomaterials, Nanostructres and Applications, held at the University of Delhi between 19-21 December 2007. Particularly significant were discussions with Prof. Arun Chattopadhyay from the IIT Gwahati in the area of conducting polymer fibres for sensors and actuators, and with Dr Bipasa Bose from Reliance Life Sciences Pty Ld, Mumbai in the area of bionics – namely using CNT substrates for the growth of stem cells.

ACES would be interested in bringing these leading Indian researchers to our laboratories in Wollongong to develop mutually beneficial collaborations.

Mr Rahul Agrawal (from IIT Bombay) spent a three month period investigating a novel magnesium biocompatible battery system with Dr Bjorn Winther-Jensen at Monash.

IRAN

Prof. Kane-Maguire delivered the Keynote Address at the 6th Textile Engineering Conference in Iran, discussing "Organic Conducting Fibre: Wearable to Medical Implants" and "Nanostructured electrodes as new bionic materials".

Whilst in Iran, Prof. Kane-Maguire was also a guest lecturer at the University of Guilan, Tabriz University and Isfahan University of Technology (I.U.T.). A formal collaborative research agreement was established with IUT, which is one of the top universities in Iran. This agreement will facilitate student and researcher exchanges, as well as the opportunity to pursue joint research projects.

Professor Leon Kane-Maguire addresses a scientific audience in Iran

IRELAND

Research links with **Dublin City University** were expanded during 2007 to include, optically switchable surfaces and electrochromatography. Research activities in novel sensing technologies including wearable electronics were also expanded and a number of key publications have emerged. Prof Wallace and Prof Diamond (DCU) received ARC Linkage support to further develop these latter aspects. A joint Symposium highlighting the collaborative research activities was hosted by DCU in September 2007.

Dr Karl Crowley and Dr Aoife Morrin (DCU Research Fellows) spent time at ACES – UoW working on aspects of inkjet printing for new sensor and microfluidics developments. Dr Rob Byrne spent time at ACES - Monash working on benzospirans for sensor applications. Student Kevin Fraser from ACES – Monash will visit DCU in early 2008 to continue the work.

ACES – UoW hosted the first two (National University of Ireland, Maynooth) Endeavour Fellows from the Emerald Isle, Clare Harley and Gillian Hendy. The two PhD students worked on different aspects of nanostructuring to improve controlled drug release and new biosensing technologies.

Links with Trinity College also continued, with ACES hosting two final year Nanotechnology students from Trinity.

JAPAN

Professor MacFarlane presented a Plenary lecture on Ionic Liquids at the 2nd Congress on Ionic Liquids ("COIL-2") in Yokohama, August 2007. This biennial conference is the focal point of ionic liquids research in the world and typically attracts 500- 600 people. COIL-2 had presentations on a wide variety of topics including a wide range of electrochemical applications of ionic liquids. The ACES – Monash team was well represented by 10 staff and students, all of whom presented talks or posters. A range of valuable new collaborations was established.

Professor Forsyth also presented an invited lecture at COIL -2 entitled "Taming reactive metals using ILs".

The ACES - Monash group has been selected to be the host of the next COIL meeting which will be held in Cairns in June 2009.

Gordon Wallace (ACES/IPRI), Emmet O'Reilly (NCSR), Robert Forster (NCSR), Sonia Ramirez (NCSR), Shannon Little (ACES/IPRI), Sarah Brady (NCSR), Yanzhe Wu (ACES/IPRI, NCSR), Dermot Diamond (NCSR).

Doug is seen here accepting the COIL trophy (a large piece of Salzburg salt).

KOREA

Researchers from Hanbat University, Prof. Don Won Kim and Prof. Ko spent sabbaticals at the ACES - Monash and ACES - UoW nodes respectively during 2007. A number of important papers in the polymer battery/capacitor area have already emerged from this important collaboration.

Our links with **Hanyang University** (Prof. Kim) have also been most productive in 2007, resulting in the development of several new artificial muscle technologies. (Mr Changkee Lee and Mr Min Sup Kim from Hanyang spent 2 months carrying out collaborative research at ACES – UoW).

Prof. David Officer (ACES - UoW) with Prof. Margaret Sheil (UoW DVC Research), together with Dr Byung Kim (IPRI), visited Daejon, Korea. They were invited to participate in celebrations for the 80th Founding Anniversary of **Hanbat University**. Prof. Officer gave the initial presentation at the International Symposium on University-Industry Collaboration.

MALAYSIA AND SINGAPORE

Professor Forsyth presented a keynote lecture at the International Conference on Advanced Materials and Nanostructures in Malaysia, May 2007.

Professor MacFarlane organised and chaired a session on Ionic Liquids at the 12th Asian Chemical Congress in Kuala Lumpur, August 2007.

At the International Conference on Materials for Advanced Technologies, in Singapore, July 2007, Dr Winther Jensen presented an invited talk on Intrinsically Conducting Polymers.

NEW ZEALAND

Our association with the MacDiarmid Research Institute in New Zealand and its members (especially at Massey and Otago Universities) continues to grow. In 2007 we joined forces with our New Zealand colleagues to initiate the Alan MacDiarmid Symposium. The event will be held every year to celebrate the achievements of Alan's research and in appreciation of his strong support for both ACES and the MacDiarmid Institute. The symposium consists of presentations from early career researchers and PhD students in recognition of Alan's great enthusiasm for the younger generation of scientists.

Left: Professor David Officer delivering the initial presentation at the International Symposium on University-Industry Collaboration on 'Energy transfer and nanostructures: From solar cells to bionics'. Right: Professor David Officer and Professor Margaret Sheil (UoW DVC Research), visiting Daejon, Korea to participate in celebrations for the 80th Founding Anniversary of Hanbat University.

THAILAND

ACES has established strong collaborative links with Prof Sukon Phanichphant's laboratory at **Chiang Mai University** in Thailand. Sukon visited UoW during 2007 and jointly supervised PhD student Chonlada Dechakiatkrai, who also spent several months in the ACES laboratories during 2007.

Areas of collaboration include formation of novel TiO_2 nanostructures and have led to a number of joint publications during 2007.

UK

Professor Forsyth visited Prof. James Durrant and gave a seminar on Plastic Crystals at Imperial College, Sept 2007. Professor Forsyth visited Prof. Mark Smith (Warwick) and Dr. Alison Davenport (Birmingham) in the UK, Sept/Oct 2007, as part of a recently awarded EPSRC grant to facilitate an international collaboration using /developing NMR techniques to understand surfaces of reactive metals upon exposure to particular environments.

Professor Forsyth working on the 14 Tesla magnet at Warwick.

Professor Forsyth is seen pictured working on the 14 Tesla magnet at Warwick.

Professor Forsyth also visited Prof Saiful Islam at Bath University during this trip to discuss collaborative work.

Miss Alison Chard visited ACES – Monash for three months from Birmingham University, UK as an occupational trainee undertaking a research project on the use of electrochemical techniques to investigate corrosion inhibition of aluminium alloys.

Dr Jenny Pringle visited Prof. James Durant and Dr Brian O'Regan at Imperial College, London, in July 07. Discussion primarily related to performing transient absorption studies on dye-sensitised solar cells containing ionic liquid electrolytes, in addition to meeting a number of PhD students. This visit was partially funded by ICOS DEST ISL. During the trip, Dr Pringle also attended the RSC conference MC8: Advanced Materials by Chemical Design, at University College, London.

USA

A strong collaborative effort involving Prof Austen Argell (**Arizona State University**) and his group continued during 2007. These studies provide valuable theoretical insights into the behaviour of novel electrolytes.

Links with Prof Richard Kaner (**UCLA**) were also consolidated during 2007. Visits by Christina Baker and Scott Gilje (graduate students from Ric's group), enabled us to continue studies on flash welding nanoparticles and to initiate studies into Graphene.

Links with Prof Ray Baughman (Thermal Energy Harvesting) and Prof Anvar Zhakidov (novel solar cell technologies) at the **University of Texas, Dallas** have also continued throughout 2007.

ACES INTERNATIONAL SYMPOSIUM 7-9 FEBRUARY 2007

The Australian Research Council Centre of Excellence for Electromaterials Science (ACES) hosted its annual three-day international symposium from 7-9 February 2007 at the University of Wollongong. World class researchers discussed synthesis, characterisation and applications of electromaterials in a range of important fields. The symposium attracted over 150 delegates from the USA, China, Japan, England, Germany, Ireland, Korea and Australia. CSIRO was well represented, as were industry representatives from the materials, energy and medical devices sectors.

Key presentations included developments in electromaterials science, and in particular how nanotechnology has advanced materials research and material applications in the areas of bionics and energy:

- A paper delivered by **Professor Siegmar Roth** (Max-Planck Institute for Solid State Research, Stuttgart, Germany). Professor Roth is an internationally recognised leader in nanostructured materials research and provided insights into the latest advances in generating carbon nanotube thin films optimised for use as electrodes or transistors.
- A paper delivered by **Professor Mark Cook** (St Vincent's Hospital Melbourne/University of Melbourne). Professor Cook is a neurologist specialising in the treatment of epilepsy which is the commonest serious neurological disease afflicting the population. Attention has now turned to promising new methods of polymer-based drug delivery systems to neural tissue. St Vincent's is working in collaboration with University of Wollongong researchers.
- A paper delivered by **Professor Zi Feng Ma** of Shanghai Jiao Tong University, China, on strategies and progress on the development of fuel cell electric vehicles in China. Major advances have been made in this field using devices to power vehicles with zero emissions into the atmosphere. The University of Wollongong recently signed a collaborative research agreement with Shanghai Jiao Tong University.

The symposium included an overview of advances in electromaterials from the Centre's Executive Research Director, Professor Gordon Wallace. Key Centre researchers also presented their latest results on topics such as nanostructured (extremely minute) electronic devices, optimising material properties to enhance cell growth for bionics, nanocomposite materials for use in lithium rechargeable batteries, and artificial photosynthesis using nanostructured materials for light harvesting.

A key focus for symposium organisers was to highlight the research and impact of young researchers in the area, achieved through inclusion of a Fellows session in the oral program, and extensive poster sessions for post-graduate students and post-doctoral fellows. The oral program was well received, with highly talented and dynamic ACES Fellows presenting their research work on topics ranging from new techniques for producing nanostructured materials, to their inclusion into devices for electronics & energy applications.

The poster sessions provided the opportunity to cover a vast range of topics, with two evening sessions facilitating networking and in-depth discussion amongst delegates. Poster prizes sponsored by the Australian Research Council Nanotechnology Network were hard earned, with 2 of a short-listed 5 entries receiving a certificate and cash prize after defending their posters during the session and subsequently presenting an oral snap-shot of their posters in a time limit of 90 seconds to the entire conference.

Delegates were saddened to learn of Nobel Laureate, Professor Alan MacDiarmid's passing during the symposium, with various tributes to his impact on electromaterials science added into the program.

The event was made possible with support from both State and Federal levels of Government, in particular from the Australian Research Council Nanotechnology Network who subsidised the attendance of students and early career researchers.

INTERNATIONAL FOCUS

- The Annual ACES meeting in Australia has also become a major focal point attracting significant attention and international visitors to Australia (see p26).
- ACES researchers are in high demand – invited to present our most recent findings at a diverse range of international research meetings (see Appendix III).
- ACES also hosted a large number of visitors from research organisations and industry from within Australia and overseas (see Appendix IV).

Outreach Activities

LAUNCH OF ENERGY FUTURES NETWORK

APRIL 2007

On 19 April 2007 the Deputy Vice-Chancellor (Research), Professor Margaret Sheil, launched the University of Wollongong's Energy Futures Network as part of Sustainability Week 2007.

The UoW Energy Futures Network is a new initiative that brings together researchers from a broad range of disciplines to maximise the effectiveness of UoW's involvement in the global effort to develop sustainable energy supply systems and to better understand the impact that the use of energy has on the environment.

Following the launch, **Professor David Officer (ACES - UoW)** presented a talk entitled: "Shedding Light on a Sustainable Energy Future: Is Artificial Photosynthesis the Key?" Sustainable economic growth in Australia and globally requires cheap renewable, environmentally acceptable, energy resources. Professor Officer discussed the potential of artificial photosynthesis-based solar cell technologies and highlighted the advances made in ACES and overseas.

KEY SUPPORT FOR INNOVATION FESTIVAL

MAY 2007

The University of Wollongong hosted seven events in support of the Australian Innovation Festival and the Illawarra Innovation Showcase, conducted from 26 April to 27 May and from 7 May to 13 May, respectively. More than 42 organisations took part with the official opening held at the Port Kembla Port Corporation on Monday 7 May. The Minister for Police and Minister for the Illawarra, Mr David Campbell, officially opened the Showcase.

Innovation Festival events included:

Innovation on Foot. People were urged to join this free, two hour walking tour of UoW's main campus highlighting what's new and innovative at the University. The tour included a visit to the new Graduate School of Medicine and various research institutes, including the **Intelligent Polymer Research Institute** node of **ACES** and the Smart Foods Centre.

PUBLIC FORUM ON ENERGY OPTIONS - HOSTED BY WOLLONGONG SCIENCE CENTRE

MAY 2007

The Innovation Showcase continued this week with a Public Forum on Energy Options for 2020 held on 10 May at the Science Centre and Planetarium. The thought-provoking and informative forum was moderated by ABC Radio's Simone Whetton and presented by some of the country's leading experts in their fields.

Professor David Officer, an organic chemist and Professorial Fellow in **ACES at UOW,** delivered a presentation on solar energy. Professor Officer's research into solar cell technology is in developing 'intelligent materials' to emulate photosynthesis. He was recently awarded the New Zealand Institute of Chemistry Hort Research Prize for Excellence in the Chemical Sciences.

Demonstrating his pedal power is UoW's Professor David Officer (right) pictured with (l to r) Associate Professor Martin Sevior from the University of Melbourne; Science Director with the CSIRO Division of Energy Technology, Dr John Carras and ABC Radio's Simone Whetton.

He was joined by Dr John Carras who is the Science Director with the CSIRO Division of Energy Technology. Dr Carras discussed his research into fossil fuels as well as spontaneous combustion and greenhouse gas emissions. Associate Professor Martin Sevior from the University of Melbourne also spoke on the subject of nuclear energy and his research into the field of experimental particle physics.

ST VINCENT'S CENTRE FOR NEUROSCIENCE AND NEUROLOGY RESEARCH EXCITABLE CELLS WORKSHOP - MELBOURNE

MAY 2007

Professors Wallace, Spinks and MacFarlane, of ACES, joined the St Vincent's Centre for Neuroscience and Neurology Research excitable cells workshop in Melbourne.

Prof. D. MacFarlane (ACES - Monash), Prof. M. Cook (St. Vincent's Hospital Melbourne), Prof. G. Wallace (ACES UoW), Prof. D. Diamond (Dublin City University, Ireland), Prof. R. Kapsa (UoW - St. Vincent's Hospital Melbourne) at the St Vincent's Hospital Neuroscience Research Retreat, Melbourne in May 2007.

Professor Wallace described recent work on conducting polymers and nerve cells, while Professor Spinks covered developments in artificial muscles and Professor MacFarlane described exciting recent results on the use of ionic liquids as new protein storage media.

HEALTH OPTIONS FOR 2020 - WOLLONGONG SCIENCE CENTRE FORUM

SEPTEMBER 2007

The Health Options for 2020 forum was hosted by the Wollongong Science Centre. Professor Gordon Wallace was one of a panel talking to a community audience. Other invited speakers included Professor Wilf Yeo and Assoc Professor Ulrich Bommer from the Graduate School of Medicine and Professor Linda Tapsell from the Smart Foods Centre at UoW.

Professor Wallace spoke of nanobionics where new materials have the potential to bridge the interface between electronics and biology. These materials can perform as actuators or 'muscles' that have the ability to work under a high extension and a high load. When biological molecules are incorporated into the materials it is possible to control interactions with cells, so these materials may eventually find use in medical implants. Already bionics today manipulates hearing (cochlear implant) and sight. Professor Wallace also spoke about 'talking knee straps' that aid medical officers with teaching AFL football players the correct landing techniques so as to reduce non-contact anterior cruciate ligament injuries.

The forum attracted a packed crowd to the Science Centre and Planetarium

PRINT, RADIO AND TV COVERAGE

ACES research, with the focus on nanotechnology and the use of this in energy conversion/storage as well as medical bionics, gives rise to highly topical findings. The significance of these outcomes is obvious to the general public and as such is attracting significant media attention (for full listing see Appendix V).

OCTOBER 24, 2007

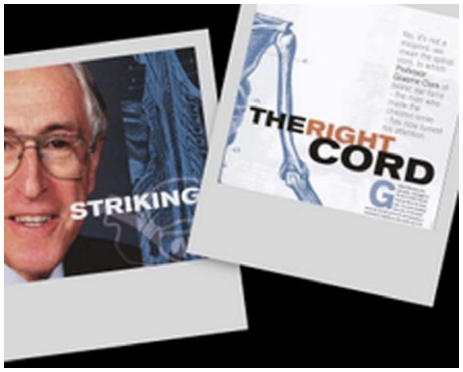
ABC TV's Catalyst program featured Gordon Wallace who discussed how electrotextiles can contain sensors to allow people to do a range of things such as exercise properly, improve golf swings and even change the colour of their clothing.

OCTOBER 2007

"Striking the Right Cord" in **Honda, THE MAGAZINE** Issue 41, Spring 2007. This article is an interview with Professor Graeme Clark about his taking on the challenge to "stem the tide of consequences flowing from spinal cord injury".

JUNE 11, 2007

Dr Yanhze Wu from Dublin City University and ACES cycles up a storm in this article featured on the BBC website, "Smart Clothes to Monitor Health."



Dr Yanzhe Wu cycling up a storm along side the BIOTEX sensor. Featured in BBC news article "smart clothes to monitor health".

Prizes and Awards

STUDENTS

Shannon Little in February 2007 was awarded the CRC Polymers Prize for the Best Honours thesis (in Polymer Research) in Australia for 2006.

Tracey Markley, **Monash/ACES** won the Australian Corrosion Association Postgraduate Best Paper Award at the Corrosion and Prevention meeting in Sydney in November 2007.

Brianna Thompson, IPRI/ACES was awarded first prize in the poster competition at the Australian Research Council Centre of Excellence for Electromaterials Science (ACES) annual three-day international symposium from 7-9 February 2007.

Brianna Thompson was also nominated by the ARC Nanotechnology Network as one of five Australian graduate students to participate in the "HOPE Meeting" being organised by the Japan Society for the Promotion of Science to be held in Tsukuba 24-28 February 2008. The aim of the meeting is to give opportunities to graduate students from countries in the Asia-Pacific region to engage in interdisciplinary small-group discussions with Nobel Laureates and other distinguished scientists as well as with research students from other countries. Speakers and mentors at the meeting will include Dr. Leo Esaki (1973 Nobel Laureate in Physics), Dr. Alan J. Heeger (2000 Nobel Laureate in Chemistry), Dr. Robert B. Laughlin (1998 Nobel Laureate in Physics), Dr. Heinrich Rohrer (1986 Nobel Laureate in Physics) and Dr. Hideki Shirakawa (2000 Nobel Laureate in Chemistry).

RESEARCH FELLOWS

Joselito Razal: Awarded ARCNN Overseas Travel Fellowship and additional funding from ARC ACES (UoW) and the Robert A. Welch Foundation (UTD), to travel to NanoTech Institute at the University of Texas at Dallas in June 2007.

Jun Chen: Awarded a grant in aid of $9500 from Australian Academy of Science for a scientific visit to Europe in 2008.

Dr Chee Too, Dr Andrew Minett and Dr Jun Chen: Awarded $52 800 for an Australia-China special fund for scientific and technological cooperation, a component of the International Science Linkage programme (ISL) through the Australian and Chinese Academy of Science. This funding allows for travel/ scientific visits to further expand our collaborative research activities in the area of fuel cells with Shanghai Jiao Tong University, 2008-2010.

Dr Pringle was awarded a Queen Elizabeth II Fellowship from the ARC to work on "Advanced Ionic Materials for Organic Photovoltaics". This is a five year program starting in January 2008

Dr Dan Li, Dr Peter Innis and Prof Leon Kane-Maguire: Awarded $50,000 for an Australia-China special fund for scientific and technological cooperation, a component of the International Science Linkage programme (ISL) through the Australian and Chinese Academy of Science.

This funding is for establishing collaborative research in Novel Electronic and Optoelectronic Devices based on Electroactive Nanofibres, with the University of Electronic Science and Technology at Chengdu, China.

Dr Jun Chen was the UoW Trailblazer Open Winner for his presentation on "Nanostructured Flexible Carbon Nanotube Electrodes for Energy System." The University of Wollongong's annual Trailblazer innovation competition was developed to reward innovative ideas and early-stage research, which have the potential to benefit the community, industry or business as well as generate a financial return. With $14,000 in prize money, the competition also rewards and stimulates innovative thinking.

CHIEF INVESTIGATORS

Professor Doug MacFarlane and Professor Gordon Wallace were elected as Fellows of The Australian Academy of Science, May 2007.

Professor Doug MacFarlane was awarded a Federation Fellowship by the ARC, commencing 2007, for work in "Biocompatible ionic liquids – Preserving bioactive structure and function". Doug works at Monash University in physical chemistry and is Program Leader in the ACES Energy Storage area.

In May 2007 **Professor Graeme Clark** received the 2007 Klaus Joachim Zulch prize for his outstanding achievements in basic neurological research and for developing the multi-channel Cochlear implant (Bionic Ear). He shared the prize with Dr John Donoghue who leads the brain science program at Brown University in the United States. The Zulch prize is Germany's highest award in neuroscience, and is made by the Max Planck Institute which is ranked by the Times Education Supplement in 2006 as the top research institute in the world.

Professor Yi-Bing Cheng was elected to the Fellowship of the Australian Academy of Technological Science and Engineering (ATSE).

OTHER FUNDING AWARDS

The Victorian Government, as part of its Energy Technology and Innovation Strategy has granted $6M to a consortium consisting of ACES - Monash, University of Melbourne (Professor Andrew Holmes) and CSIRO for Solar Cell research. The consortium also includes the companies Securency P/L, BP Solar, Merck, Bluescope and Nanovic. The consortium will work over the next 3 years on the development of printable solar cell technologies.

The NSW Government has provided a $1 million grant to the University of Wollongong to support research and development in the field of nanotechnology. ACES, with the University of Newcastle, will provide the Materials Node of the Australian National Fabrication Facility (ANFF). The ANFF provides Australian researchers with state-of-the-art fabrication capability for nanoparticles, nanostructures, nanosensors and nanotechnological devices.

It is a seven-node facility, with nodes distributed throughout Australia, drawing on existing infrastructure and expertise. Construction is well advanced on the new $28m Innovation Campus building which will house the UoW node, anticipated to be fully operational by 30 June 2008. Funding has been provided from the Federal Government's National Collaboration Research Infrastructure Strategy (NCRIS) and the NSW Government.

Under the Fabrication Capability of the **National Collaborative Research Infrastructure Strategy (NCRIS),** UOW has been awarded $1.5 million from NCRIS and NSW State Development funds to further develop fabrication of novel polymer and ceramic nanomaterials, and organic electronic nano-devices. The funds will be used for infrastructure upgrades and positions for senior research fellows in the Institute for Superconducting and Electronic Materials led by Prof. Shi Dou and in the Intelligent Polymer Research Institute (ACES) led by Prof. Gordon Wallace.

Professor Gordon Wallace (left) and **Professor Doug MacFarlane** (right) were elected as Fellows of The Australian Academy of Science, May 2007.

ACES PROVIDES A PLATFORM FOR NEW ARC DISCOVERIES IN 2008

The ARC Centre of Excellence for Electromaterials Science continues to attract highly talented young researchers from around the world. In the recent announcement of ARC grants to commence in 2008, Dr Jenny Pringle was awarded a QEII Fellowship to work on ionic liquids for solar cell applications, based at ACES -Monash. Dr Katya Izgorodina was also awarded an Australian Postdoctorial Fellowship to work as part of ACES – Monash in the modelling area. Katya and Jenny join A/Prof. Peter Innis, Dr Dan Li and Dr Andrew Minett as ARC QEII Fellows and Dr Bjorn Winther-Jensen, Dr Udo Bach and Prof. Doug MacFarlane as ARC Fellows associated with ACES.

This assembly of highly skilled researchers and world class infrastructure available at all of the ACES nodes (UoW, Monash University, St Vincent's Hospital / Bionic Ear Institute) provides a fertile environment for the development of research streams not anticipated at the establishment of the Centre. As such, ACES personnel compete within the ARC Discovery rounds to have research projects associated with these initiatives funded.

For example, in 2008 the following ARC Discovery Grants involving ACES personnel have been funded.

- **Functionalised Nanostructured Polythiophenes: Novel Platforms for Bionics**. G. Wallace, D. Officer, R. Kapsa, S. Moulton (BEI & UoW) - **DP0877456**
- **Novel Graphene Nanostructures: Modelling, Synthesis, Fabrication and Characterisation.** C. Zhang, D. Li, F. Liu, R.B. Kaner, Y. Jiang (UoW) - **DP0879151**
- **Novel 3D Carbon Architectures for Fuel Cell Applications**. J. Chen, A. Minett (UoW) - **DP0877348**
- **Pushing the Limits: Fabricating Micro and Nano Actuators.** G. Alici, G.M. Spinks, J.M. Cairney (UoW) - **DP0878931**
- **Advanced Ionic Materials for Organic Photovoltaics.** Dr JM Pringle – QEII Fellowship (Monash) - **DP0879480**
- **Computational approaches to selection and design of ionic materials.** Dr E.I. Izgorodina – APD (Monash) - **DP0880072**
- **Novel network polymers photoinduced plasticity.** Prof W.D. Cook, Prof C.N. Bowman, Dr T.F. Scott, Dr S.H. Thang, Dr J. Sun (Monash) - **DP0877382**

In recognizing that excellent people require excellent facilities to remain at the cutting edge, the ARC through the LIEF scheme has also provided funding to acquire state-of-the-art fabrication and characterization facilities for proposals involving ACES researchers.

FABRICATION AND CHARACTERISATION FACILITY FOR ORGANIC SOLAR CELLS (LE0883019)

A combined organic solar cell fabrication and characterization facility that was previously available only through overseas collaborations will be established in the ACES laboratories at UoW. It will enable an internationally recognized team of approximately 27 researchers including research fellows and PhD students to: (1) efficiently integrate novel electromaterials into state-of-the-art photovoltaic devices and (2) study electron transfer and transport dynamics in order to reveal the material properties that govern the electronic behaviour of these materials.

AN ANALYTICAL FIELD EMISSION GUN SCANNING ELECTRON MICROSCOPE (LE0882613)

An analytical field emission gun scanning electron microscope is an advanced tool for the characterisation of alloys, nanomaterials, superconductors and polymers. The instrument's advanced characterisation capabilities will significantly enhance the effectiveness of three material-based research Institutes and ACES researchers at the University of Wollongong, as well as collaborative research with BlueScope Steel. The research is directly aligned to the National Research Priority of Frontier Technologies for Building and Transforming Australian Industry.

ION BEAM NANOFABRICATION AND CHARACTERISATION FACILITY FOR ADVANCED MATERIALS RESEARCH (LE0882821)

This new facility will enhance progress in nanotechnology, biotechnology and materials sciences, not only training the next generation of researchers to drive these critical areas, but maintaining Australia's track record as an innovator and developer of advanced materials.

Industry/End-User Liaison

The key role of the Centre Business Development Officer (BDO) is to develop and maintain links with end users of the Centre's outcomes. These include industry, business, education and community sectors. 2007 saw the Centre meet a number of key objectives for end user engagement, most notably the establishment and operation of an End Users Committee.

THE END USERS COMMITTEE

The BDO, with key Centre staff, operates the End Users Committee, which is an industry forum facilitating input from industrial partners of the Centre, on the strategic direction of scientific research activities, methods of end user engagement and commercial opportunities. The 7 member committee currently compromises Evan Evans (BlueScope Steel), Jim Patrick (Cochlear), Phil Aitchison (Cap-XX), Tan Truong (DSTO), Ray Shaw (Rio Tinto), James Nicholson (Schefenacker) and Peter Murphy (Ian Wark Research Institute/ CAMR).

The inaugural meeting was held on 30 January 2007 and raised issues such as appropriate communication mechanisms, industry input into the training of PhD students, accessing research and potential roles in commercialisation of Centre technologies.

The Centre's full scientific ambit was presented to Committee members in the 2nd End Users meeting, which took place on 27 June 2007. The relevant Centre Program Leaders presented a brief summary of goals, achievements and future directions for projects within the five research programs. Formal feedback to this material was facilitated through a 3rd End Users meeting, held on 22 November 2007. The outcomes of this meeting were presented to the International Advisory Board meeting in February 2008 (Refer to IAB Report).

IMPLEMENTATION OF REGULAR CENTRE NEWSLETTER AND UPDATED PROMOTIONAL MATERIAL

Launched in March 2007, three editions of the online Centre newsletter were distributed via email to approximately 250 recipients and published to the Centre website during 2007. Each edition regularly featured current news items of the quarter, recent publications and selected projects relating to core research areas: Electromaterials (Mar 07), Energy Conversion & Storage (June 07) and Bionics (Oct 07). Facilities snapshots, profiles of staff members, as well as reports on the Centre's global interactions including invited presentations by Centre CIs, international visitors and student exchange visits were indicated.

The Centre also used the newsletter as a way of communicating upcoming events and opportunities to an extended audience of academic and industrial contacts with a specific Calendar and Employment section.

During 2007, the Centre finalised the design and content of the Centre's promotional material, with the assistance of University of Wollongong's Print Department. This design forms the core of hard copy and electronic presentations by Centre members, and will lead to easy recognition of Centre activities by external audiences. Detailed inserts, developed in consultation with Program Leaders, contain information about the Centre, its staff and facilities and the ARC sponsored research programs, and have been made available to the numerous industrial visitors through the Centre. Team profile information was updated in September 2007, and characterisation/fabrication facilities, (including equipment available under our NCRIS node) was finalised towards the end of the year.

SYMPOSIA AND RELATED EVENTS WITH INDUSTRIAL AUDIENCES

The Centre invested significant time into organising symposia and related events that involve industry, and provide the opportunity to showcase Centre research to a wider audience. In the past 2 years, the Centre had record industry attendance at its annual February symposium, and successfully ran Carbon Nanotube and Ink Jet Printing workshops in March and December 2007, respectively (as detailed in the Education & Training section of this report).

TARGETED WORKSHOPS

ACES has initiated a targeted workshop program in order to develop new research collaborative links with End Users not in the commercial sector.

An ACES-DSTO workshop was hosted by DSTO at Fisherman's Bend on November 8th 2007. The workshop attracted participants from three different DSTO Divisions

- Maritime Platform
- Air Vehicles
- Human Protection and Performance

and provided insights into DSTO requirements in areas such as energy conversion, energy storage and electronic textiles (wearable sensors).

Management Arrangements

The Governance/Organisation Chart for ACES is shown below as Scheme 1. The 2007 International Advisory Board (IAB) meeting, held on 7th February, was chaired by Prof. Ray Baughman, following the withdrawal of Prof. Alan MacDiarmid from the meeting due to illness. It was only a few days later that we sadly learned of Alan's death. As indicated earlier, an annual MacDiarmid symposium will continue his memory and influence on ACES. Despite this great loss, ACES was fortunate to attract Dr Bridget Ogilvie as the new Chair of the IAB for 2008.

Dr Ian Sare, a member of the DSTO Senior Leadership Team, also agreed to join the Board in 2008.

Our staff would like to thank Profs. Margaret Sheil and Peter Robinson who resigned from the board in 2007. Both Margaret and Peter have provided support and advice to ACES and its researchers over a number of years.

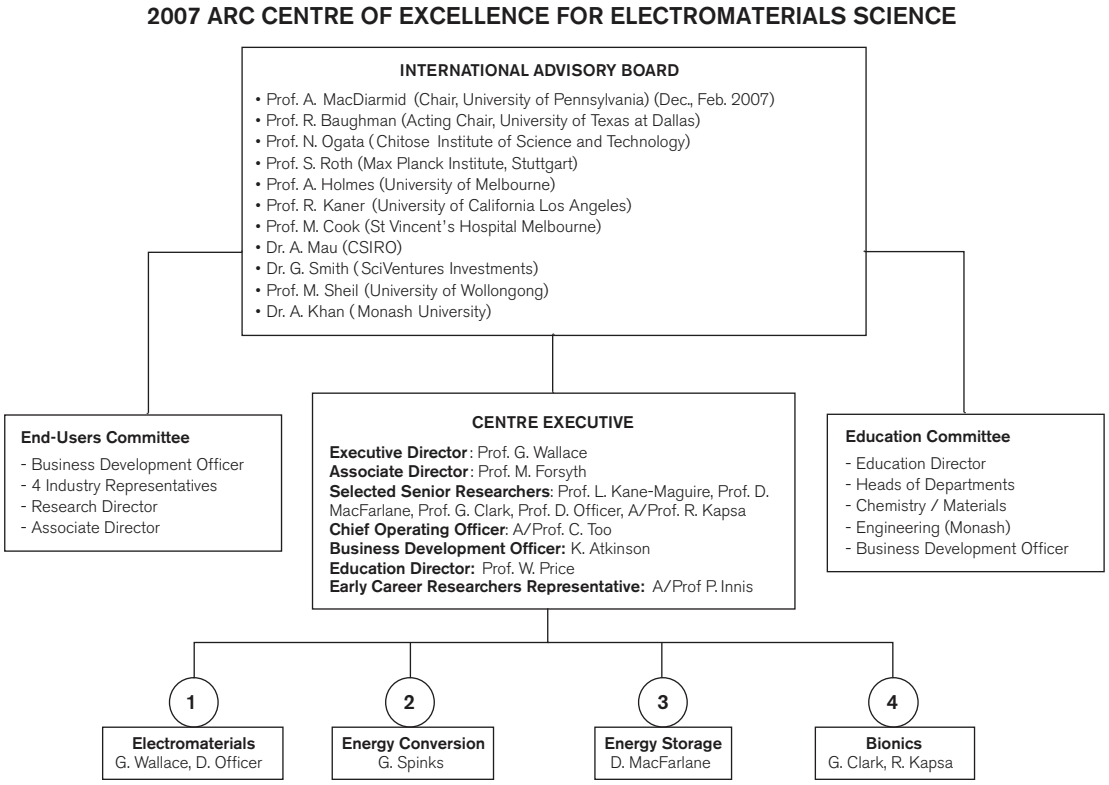
The ACES Executive Committee was largely unchanged from 2006 with Professor Officer joining the Committee as a full member. Seven Executive Committee meetings were held during 2007.

The Education Committee consisted of: William Price, Geoff Spinks, Kaylene Atkinson, Peter Innis, Toni Campbell from the University of Wollongong, and Yibing Cheng from Monash University. The Education committee met regularly during 2007.

The End-Users Committee consisted of: Evan Evans (BlueScope Steel), Jim Patrick (Cochlear), Phil Aitchison (Cap-XX), Tan Truong (DSTO), Ray Shaw (Rio Tinto) James Nicholson (Schefenacker) and Peter Murphy (Ian Wark Research Institute/ CAMR). The End-Users committee met three times during 2007.

The 2007 Full Centre Meeting was convened in October at St Vincent's Hospital, Melbourne. A list of Centre staff is given in Appendix VI.

The ACES Intellectual Property Register is given in Appendix VII.



Scheme 1. Organisation Chart for ACES

Publications

The target for 2007 was 35 refereed publications of which at least 50% would have an impact factor greater than 2. We have greatly exceeded these targets with a final result of 72 refereed publications of which 51 have an impact factor greater than 2. The publications list is given below.

ARC CENTRE 2007 PUBLICATIONS LIST

(IF = Impact factor)

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Performance Indicators

The Key Result Areas and Performance Measures Schedule for the Centre is given below. In general the performance of the Centre has exceeded our targets. In particular, there were 72 refereed publications of which 51 had an impact factor greater than 2, 14 postgraduate students recruited, 6 postgraduate completions, 3 national/international workshops, 29 invitations to international conferences, 32 visits to leading international laboratories, 44 media reports, 37 international visitors, 3 patents lodged, and 7 new organisations recruited to collaborate with the Centre.

SCHEDULE E

KEY RESULT AREAS AND PERFORMANCE MEASURES

Key Result Area	Performance Measure	Target	2005 Outcome (July-Dec)	2006 Outcome	2007 Outcome
Research findings	Quality of publications	At least 50% of journal articles in journals with impact factor >2	No target	33	51
	Number of publications	2006 – 30 2007 – 35 2008 – 40 2009 – 45 2010 – 50	No target	61	72
	Number of provisional patents lodged	2 per annum	2	10	3
	Invitations to address and participate in international conferences	6 per annum	0	18	29
	Invitations to visit leading international laboratories	6 per annum	0	22	32
	Number and nature of commentaries about the Centre's achievements	Print, radio, TV media, 1 per annum	8 in Print	21 in print, 2 website, 8 radio, and 5 TV	26 print, 3 website, 8 radio, and 7 TV
Research training and professional education	Number of postgraduates recruited	20 over 5 years	30	27	14
	Number of postgraduate completions	4 per annum	0	4	6
	Number of Honours students	-	0	1	
	Number of professional courses	1 per annum	0	2	
	Participation in professional courses	-			
	Number and level of undergraduate and high school courses	Undergraduate: 1 per annum. Honours: 1 per annum from 2007. Schools: 1 per annum.		University of Wollongong's Bachelor of Nanotechnology	University of Wollongong's Bachelor of Nanotechnology
International, national and regional links and networks	Number of international visitors	4 per annum	14	73	37
	Number of national and international workshops	1 per annum	0	1	3
	Number of visits to overseas laboratories	6 per annum	1	22	32

Key Result Area	Performance Measure	Target	2005 Outcome (July-Dec)	2006 Outcome	2007 Outcome
End-user links	Number & nature of commercialisation activities: Licences, assignments or options.	1 per annum	0	0	2
	Number of government, industry and business briefings	2 per annum	12	3	1
	Number of Centre associates trained/ing in technology transfer and commercialisation	2 per annum	1	2	2
	Number and nature of Public Awareness programs	1 per annum	1 Uni at the Brewery. 1 podcast. 1 Science EXPO. 1 school visit.	5 in 2006: Innovation Week, UoW Professorial Lecture series, Young Science Ambassadors Awards, ATS Health Technology Expo, and UoW Higher Degree Research Student Conference.	7: Victoria High School Science Teachers Professional Development Day, Australian Innovation Festival & Illawarra Innovation Showcase, Sustainability Week, St Vincent's Hospital Neuroscience Research Retreat, 80th Founding Anniversary of Hanbat University celebrations, UoW Professorial Lecture Series, Channel 9 TV "A Current Affair", ABC TV Catalyst program.
Governance	Breadth and experience of the members of the Advisory Board	Extensive Considerable	11 board members	12 board members	13 Board members
	Frequency and effectiveness of Advisory Board meetings	1 per annum. Minutes will be provided.		1 meeting held.	1 meeting held.
	Quality of the Centre strategic plan	Evaluated by IAB			
	Effectiveness of arrangements to manage Centre nodes	Centre Exec to meet 4 times per annum	2	6 meetings held.	7 meetings held.
	The adequacy of the Centre's Key Performance Measures	Evaluated by IAB		See IAB report	See IAB report
National benefit	Measures of expansion of Australia's capability in the priority area(s)	International Visitors : 20. International Exchange Visits : 10. International Joint Publications : 10.		International Visitors : 73. International Exchange Visits : 3. International Joint Publications : 15.	International Visitors : 37. International Joint Publications : 12
	Case studies of economic, social, cultural environmental or other benefits	1			

Key Result Area	Performance Measure	Target	2005 Outcome (July-Dec)	2006 Outcome	2007 Outcome
Organisational support	Annual cash contributions from Collaborating Institutions/Organisations	**UoW** $712.6K indicative p.a. **Monash** $257K indicative p.a. **BEI** $0 **SVHM** $0 **NSW Dept of State & Regional Development** $48,984 p.a. until 2007	**UoW** $310,000 **Monash** $95,000 **NSW Dept of State & Regional Development** $48,984	**UoW** $437,161 **Monash** $258,000 **NSW Dept of State & Regional Development** $48,984	**UoW** $746,986 **Monash** $278,430 **NSW Dept of State & Regional Development** $48,984
	Annual in-kind contributions from Collaborating Institutions/Organisations	**Years 1 to 5:** **UoW** $3,835,129 $1,093,753 $1,120,223 $1,146,511 $1,173,048 **Monash** $569,424 $583,869 $598,411 $613,051 $627,791 **BEI** $596,751 $487,451 $512,739 $539,391 $567,477 **SVHM** $553,812 $570,426 $587,539 $482,138 $498,612 **NSW Dept of State & Regional Development** $0	**UoW** $526,718 **Monash** $252,878 **BEI** $62,005	**UoW** $692,111 **Monash** $$461,566 **BEI** $557,804 **SVHM** $618,198	**UoW** $724,689 **Monash** $489,260 **BEI** $505,737 **SVHM** $539,024
	Number of new Organisations recruited to or involved in the Centre	3 over 5 years		7 recruited: Cap-XX, Schefenacker, CRC Polymers, DLG Battery (Shanghai) Ltd, Guangzhou Delong Energy Tech Ltd (China), CSIRO cluster, DSTO.	7 recruited: Bionic Technologies Australia, Australian Pipeline Industry Association, Organic Solar Cell Research, DSTO, CSIRO-Minerals, BlueScope Steel, The Hearing CRC.
	Level and quality of infrastructure provided to the Centre	-			High
	Annual cash contributions from other Organisations	-			$5000 Lions Club
	Annual in-kind contributions from other Organisations	-			

The ARC recommends that a sum of money of the order of 5% of the annual ARC Centre funding should be spent each year on Centre community awareness programs, possibly including:

- professional and technical training;
- primary and secondary school awareness;
- "front-office" service for, and interaction with, Australians end-users; and
- workshops, international visitor programs and other networking activities that engage cognate Australian researchers who might not be formally associated with the Centre.

Activity Report 2007

Our strategic objectives for 2007 fall under the core activities of the Centre.

RESEARCH PROGRAMS

The Core Activities report for 2007 will be focussed mainly on the Year 2 milestones given below. Milestones for other years (see Appendix I) will also be addressed where applicable.

P1: ELECTROMATERIALS

P1-1 Synthesis and Processing

SYNTHESIS OF NANO-ORGANIC MATERIALS

MILESTONE 5

Supply of new materials to P2-P4 (Ongoing).

Functionalised polyterthiophenes and porphyrins continued to be prepared for solar cell, actuator and battery applications in P2 and P3.

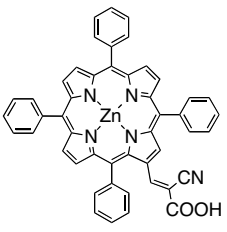
P2 – Energy conversion: A range of porphyrins **4-6** continue to be made for use in solar cells.

P3 – Energy storage: Polythiophenes **7** and **8** have been supplied to **P2** for plastic battery application, along with simpler materials such as poly(3-hexylthiophene).

P4 – Bionics: Poly(3-octylpyrrole) **9** and polythiophenes **7, 10, 11** and poly(3-hexylthiophene) have been supplied to **P4** for cell growth experiments.

MILESTONE OUTPUTS

- Highly Efficient Porphyrin Sensitizers for Dye-Sensitized Solar Cells. Campbell, W. M., Jolley, K. W., Wagner, P., Wagner, K., Walsh, P. J., Gordon, K. C., Schmidt-Mende, L., Nazeeruddin, M. K., Wang, Q., Graetzel, M., Officer, D. L. *J. Phys. Chem. C* 2007, 111 (32), 11760-11762.



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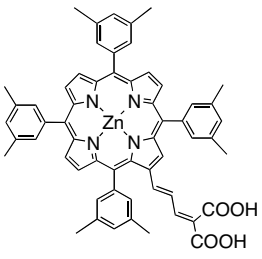

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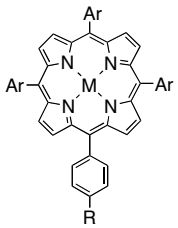

Ar = mesityl, tolyl, phenyl and p-octylphenyl.
R = CO_2H, $CHCHCNCO_2H$ or $CHCH(CO_2H)_2$.
M = H_2, Zn, Pt, Mg.

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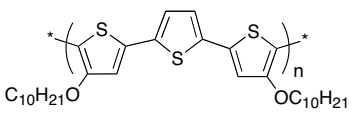

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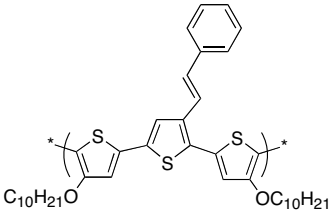

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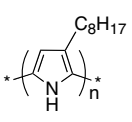

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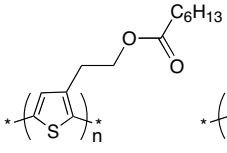

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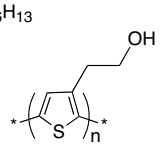

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SYNTHESIS OF NANO-INORGANIC MATERIALS

MILESTONE 6

Prepare thin-film cathodes and anodes for P3 (End Year 2).

Co_3O_4 thin films were prepared by electrochemical deposition. Si thin films, porous Au thin films and $LiMn_2O_4$ thin films were prepared by pulsed laser deposition. Co_3O_4 thin films, Si thin films, and porous Au thin films **(Figure 13)** were used for anode materials in lithium rechargeable batteries and $LiMn_2O_4$ thin films were used as cathode materials.

A multilayer mesoporous Au film showed superior characteristics compared to an ordinary Au film, with a higher specific charge passed. $LiMn_2O_4$ thin film with the lowest deposition pulse rate exhibited the best electrochemical performance, retaining a charge capacity of 48 μAh cm^{-2} μm^{-1} beyond 100 cycles.

Initially the pulsed laser deposition (PLD) technique was proposed for the ARC Centre program. As the PLD method needs expensive equipment and strict conditions, the electrochemical deposition, a very convenient method to form nanostructured thin films with lower cost under the lower temperature has been chosen to fabricate thin film Li-ion batteries. For example, the porous Co_3O_4 thin films were prepared by controlling the parameters of electrochemical deposition. This has provided new opportunities in this milestone and work has been ongoing beyond the end of Year 2.

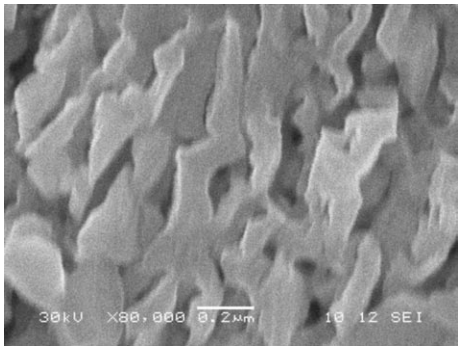
MILESTONE OUTPUTS

Mesoporous gold as anode material for lithium-ion cells. Yuan, L., Liu, H. K., Maaroof, A., Konstantinov, K., Liu, J., Cortie, M. *J. New Materials for Electrochemical Systems,* 2007, 10, 95-99.

MILESTONE 7

Development of efficient ZnS nanoparticle synthesis (End Year 2).

The reverse micelle method has been developed for the synthesis of nanocrystals (with or without the presence of dopant) and core shell structures. The method development work has used CdS as a model system, however the approach is general to most metal sulfides. The synthesis takes place in small drops of water where nanoparticles of specific size and spherical shape can be created. The size of the micelles formed, as well as the nanoparticles, were found in this work to vary in the range of several nanometres (about 1-10 nm) by Dynamic Light Scattering. The synthesis of core shell structures with high stability and high quantum yield has also been developed. The quantum yield from these particles (>20%) is some of the highest ever observed from CdS. This synthesis development milestone is now completed and materials are being routinely made for device fabrication work in P2 and P3.



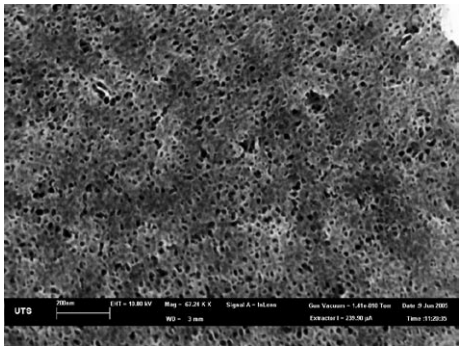


Figure 13. SEM images of mesoporous Au (a) single layer of 200 nm, (b) single layer of 100 nm.

PROCESSING

MILESTONE 12

Prepare aligned carbon nanotube samples for:

- Energy conversion: Aligned CNT-polythiophenes composite solar cells.
- Energy storage: Aligned CNT -PEDOT composites for batteries.
- Bionics: Aligned CNT-biopolymer composites for cell stimulation.

A number of approaches to functionalised carbon nanotubes have been investigated. These include covalent and non-covalent attachment. Covalent attachment results in severe compromises in both tube length (mechanical properties) and conductivity. Non-covalent attachment does not provide the degree of control in terms of loading or localisation of functional molecules.

An alternative approach to functionalising carbon nanotube structures involves the use of a conducting polymer layer to interconnect the tubes. It is envisaged that functional molecules can be incorporated into this conducting polymer layer. Alternatively, conducting polymers containing functional molecules (e.g. the nerve growth factor NT3) have been coated onto the aligned CNTs. An enhanced rate of release from these structures has been demonstrated.

MILESTONE OUTPUTS

- Flexible, Aligned Carbon Nanotube/ Conducting Polymer Electrodes for a Lithium-Ion Battery. Chen, J., Liu, Y., Minett, A.I., Lynam, C., Wang, J., Wallace, G.G. *Chemistry of Materials* 2007, 19, 3595-3597.

MILESTONE 13

Establish sol-gel methods for self assembly (End Year 2).

In this work, the sol-gel process has been used to assemble alkylammonium iodide functionalities around silica nanoparticle templates. The reaction of activated silica with triethoxysilane alkylammonium iodides gives a new range of materials that are soluble in organic solvents and which can be used in the development of electrolytes for use in dye-sensitised solar cells. We now have a variety of hydrolysable alkoxysilane with alkylammonium iodide functionalities which can be hydrolysed to self assemble a variety of new sol-gel matrices for use as electrolytes in DSSCs in P2. This work will be reported on in due course.

MILESTONE 14

Supply of fabricated structures to P2-P4 (End Year 2 then ongoing).

- A number of fibre structures as well as carbon nanotube-based electrode structures have been supplied.

FUNCTIONAL ELECTROLYTES

MILESTONE 15

Develop and characterize enhanced performance electrolytes including plastic and solid gel electrolytes (End Year 2).

Three key areas have continued to be developed under this milestone; plastic crystal electrolytes, polymer gel electrolytes and ionic liquids (ILs). Materials based on pyrrolidinium thiocyanate have been prepared and characterised using conductivity, solid state NMR and vibrational spectroscopy. The dimethyl pyrrolidinium thiocyanate material has a large solid-solid phase transition, presumably from ordered to plastic phase, at around 80°C which is accompanied by a step change in conductivity and a sudden narrowing of the proton NMR line width confirming cation diffusion. These materials are potential candidates for dye sensitized solar cell work in P2.

Work continues on characterising nanocomposite materials based on the methyl, ethyl pyrrolidinium bis(trifluorosulfonamide) plastic crystal with inorganic nanoparticles. The SiO_2 based systems have yielded the highest conductivities and lead to mechanically robust films. Solid state NMR, conductivity and thermal analysis have been used to probe the phase behaviour and transport in these materials. Thin films (less than 50 μm) were tested in a lithium metal cell and results indicate that they are excellent candidates for use as a solid state lithium thin film electrolyte.

Ionic liquids, IL mixtures, and polymer gels (containing nanoparticles) have also been prepared and characterised as possible electrolytes in Mg batteries and lithium batteries.

The discovery work in this milestone activity is now largely complete and materials are being supplied for use as electrolytes in the work in Programs 2 and 3.

MILESTONE OUTPUTS

- Nanoparticle enhanced conductivity in organic ionic plastic crystals: Space charge versus strain induced defect mechanism. Shekibi, Y., Gray-Weale, A., MacFarlane, D.R., Hill, A.J., Forsyth, M. *Journal of Physical Chemistry C,* 2007, 111(30), 11463-11468.
- Rotational and translational mobility of a highly plastic salt: Dimethylpyrrolidinium thiocyanate. Grimsley M., MacFarlane, D.R., Forsyth M. *Solid State Ionics,* 2008, 178, 1798-1803.
- A new class of proton-conducting ionic plastic crystals based on organic cations and dihydrogen phosphate. Yoshizawa-Fujita, M., Fujita, K., Forsyth, M., MacFarlane, D. R. *Electrochemistry Communications,* 2007, 9, 1202-1205.
- N-methyl-N-alkylpyrrolidinium bis(perfluoroethylsulfonyl) amide ([NPf(2)](-)) and tris(trifluoromethanesulfonyl) methide ([CTf3](-)) salts: Synthesis and characterization. Johansson, K.M., Adebahr, J., Howlett, P.C., Forsyth, M., MacFarlane, D.R. *Australian Journal of Chemistry,* 2007, 60, 57-63.
- Plastic crystal behaviour in tetraethylammonium dicyanamide. Annat, G., Adebahr, J., McKinnon, I.R., MacFarlane, D.R., Forsyth, M. *Solid State Ionics,* 2007, 178, 1065-1071.

MILESTONE 19

Supply/refinement of electrolytes for P2-P4 (End Year 2 then ongoing).

For P2 requirements, see milestones 27 and 32.

For P3 requirements, see milestone 36.

P4 requirements – biocompatible electrolytes for bio batteries.

Polymer/Ionic liquid gel and plastic crystal materials based on (pyrrolidinium bistrifluoramide) materials have been supplied to P3 activities at both Monash and Wollongong nodes. Outputs from this work have been reported in P3 milestones.

Solid state polymer electrolytes and plastic crystal electrolytes have been supplied to the solar cell activities in P2 at Monash University. In addition, plastic crystal membrane materials have been supplied to Prof. Geoff Spinks for the actuator activities.

P1-2: CHARACTERISATION

MILESTONE 20

Establishment of co-ordinated characterisation users' network (End Year 2).

- A detailed report listing all equipment, location and nominated trainers has been compiled for ACES members (IPRI, ISEM, Monash, St Vincent's/ BEI). This document provides a brief description of the characterisation equipments capabilities and uses.

MILESTONE OUTPUTS

- Characterisation report is now available on the web **http://www.electromaterials.edu.au/resources/facilities.html**

MILESTONE 21

Dr Peter Innis (QEII Fellow) will coordinate and educate on the use of conventional characterisation tools such as SEM, AFM, NMR, UV-vis and electrochemical methods, as well as specialist in-situ techniques such as Electrochemical-Electron Spin Resonance, Electrochemical-Raman and Localised Electrochemical Impedance Spectroscopy (Ongoing).

A number of in-house training courses have been delivered (see Education Milestones 55-57). Centre staff also obtain training on specialised imaging techniques as part of a UoW arrangement with NanoMNRF (relaunched as The Australian Microscopy & Microanalysis Research Facility (AMMRF)). Funding has been sourced to provide new characterisation facilities for ACES to be housed at the UoW campus.

MILESTONE 22

Utilisation of novel characterisation tools in P1-P4 (Ongoing).

- New instrumentation has been purchased at UoW.
- A training program has been established for 2008.

MILESTONE 23

Characterisation of reactive metal interfaces to develop understanding of interfacial phenomena at electromaterials interfaces and in applications including corrosion, electrowinning and energy storage and conversion (Ongoing).

Lithium metal surfaces prepared on copper foils and exposed to ionic liquid and zwitterions based electrolytes were characterized using impedance spectroscopy, solid state NMR and XPS. These complimentary characterization techniques were able to provide some understanding as to the nature of the improved lithium cell performance in the zwitterions containing electrolyte (J. Power Sources, accepted).

These same characterisation techniques also continue to be applied to magnesium alloy surfaces to characterize the surface formed on these alloys from novel ionic liquids prepared in separate ARC projects.

Aluminium alloy 2024 and 7075 surfaces that have been protected against corrosive environments via new rare earth corrosion inhibitors, supplied by our chemistry colleagues from the Centre for Green Chemistry, have also been characterised using the suite of techniques available within ACES. This has facilitated an understanding of the inhibition mechanism on these alloys.

Additional complimentary characterization methods have been developed to further determine the nature of the surface film on metal alloys; specifically profilometry methods and a new type of electrochemical cell (pipette cells) for EIS measurement of in-situ film evolution. These will be applied to a number of metal surfaces including Mg and Al alloys.

MILESTONE OUTPUTS

- The effect of zwitterion on the Lithium SEI in ionic liquid electrolytes. Byrne, N., Howlett, P.C., Macfarlane, D.R., Smith, M.E., Howes, A., Hollenkamp, T., Forsyth, M. *J. Power Sources,* 2008, in press.
- Inhibition of Corrosion on AA2024-T3 by New Environmentally Friendly Rare Earth Organophosphate Compounds (invited paper). Forsyth M., Markley T., Ho D., Deacon G.B., Junk P., Hinton B., Hughes A. *Corrosion*, 2008, in press.
- Influence of praseodymium - Synergistic corrosion inhibition in mixed rare-earth diphenyl phosphate systems. Markley, T.A., Hughes, A.E., Ang, T.C., Deacon, G.B., Junk, P., Forsyth, M., *Electrochemical and Solid State Letters,* 2007, 10(12), C72-C75.
- Passivation of reactive metals using novel chemical treatments. Forsyth, M., Lead Paper 6 (invited), *Proceedings of 'Corrosion & Prevention 2007; Sydney November 2007.*
- An investigation of a phosphinate-based ionic liquid for corrosion protection of magnesium alloy AZ31. Howlett, P.C., Zhang, S., MacFarlane, D.R., Forsyth, M. *Australian Journal of Chemistry,* 2007, 60, 43-46.
- Exploring corrosion protection of Mg via ionic liquid pretreatment. Birbilis, N., Howlett, P.C., MacFarlane, D.R., Forsyth, M. *Surface & Coatings Technology,* 2007, 201, 4496-4504.

P2: ENERGY CONVERSION

P2-2 Electromechanical Actuators

MILESTONE 30

Develop phenomenological models of ICPs and gel actuation under low voltage electrochemical stimulus, taking into account the influence of ion movements, osmotic effects, chain conformation changes and changing mechanical properties (End Year 2).

Studies relating to understanding the mechanisms of actuation occurring in ICPs and gel actuators have focused on sensors (reverse actuation) and new materials development. We discovered that ICP actuators could operate in reverse to produce a mechanical sensor. We were able to propose a mechanism for the sensor output and quantitatively estimate the magnitude of the voltage or current produced.

This work has been accepted for publication in *Advanced Functional Materials*. Further work has continued into the understanding of the change in elastic modulus of ICPs during redox cycling, as this process affects the actuation performance. Finally, a thorough review of the fundamental mechanisms of actuation in ICPs has been initiated and a review paper prepared for publication. An additional review of CNT actuation mechanisms and devices will also be published in early 2008. This milestone is completed and the new knowledge regarding actuator mechanisms will be used to produce large strain, higher strength ICPs and gel actuators in future ACES research.

MILESTONE OUTPUTS

Soft Mechanical Sensors Through Reverse Actuation in Polypyrrole. Wu, Y., Alici, G., Madden, J.D.W., Spinks, G.M. and Wallace, G.G. *Advanced Functional Materials,* 2007, 17, 3216-3222.

P4: BIONICS

P4-1 Nerve Cell Communications

P4-2 Bio-stability and biocompatibility

MILESTONE 48

An understanding of how energy transfer processes (electrical stimulation) influence these interfacial chemistries (End Year 2).

Work on Milestone 48 has focussed on the development and use of electrical stimulation to effectively release neurotrophins (NT3 and BDNF) from polypyrrole and to stimulate neuronal outgrowth from primary spiral ganglia structures (Spiral Ganglia) *in vitro*. The effect of electrically stimulated neurotrophin release was seen to augment the stimulation of neurite outgrowth compared to electrical stimulation alone.

These findings have been extended towards gaining a more detailed understanding as to how ICPs may be tailored for better control of specific biofactors' incorporation and release by electrical stimulation and towards elucidation of how electrical stimulation affects the molecular changes of proteinaceous species in contact with the ICPs.

These extended studies, incorporating molecular modelling methodologies, have already indicated a possible (hydrophobic interaction) mechanism for neurotrophin (NT3) attachment to and release from polypyrrole. Further work will be carried out in this milestone in order to achieve this.

MILESTONE OUTPUTS

- Optimizing the incorporation and release of a neurotrophic factor using conducting polypyrrole. Thompson, B.C., Moulton, S.E., Ding, J., Richardson, R., Cameron, A., O'Leary, S., Wallace, G.G. and Clark, G.M. *J Cont. Rel.,* 2007, 116, 285–294.
- The effect of polypyrrole with incorporated neurotrophin-3 on the promotion of neurite outgrowth from auditory neurons. Richardson, R.T., Thompson, B., Moulton S., Newbold C., Lum, A.G., Cameron, A., Wallace, G.G., Kapsa, R., Clark, G., O'Leary, S. *Biomaterials,* 2007, 28, 513–523.

P5: ETHICS

P5-1 Biosystems, Electromaterials and Commodification of Human Health

MILESTONE 51

An understanding of the social-legal and ethical context of developments in bionics (End Year 2).

Preliminary research was undertaken on the rapidly changing socio-legal context of developments in bionics in Australia (and in international developments, e.g. UNESCO).

A paper on the social and ethical implications of bionics, human enhancement and the regulation of nanotechnology has been prepared.

MILESTONE OUTPUTS

- Dodds. S. Nanotechnology: social and ethical issues. Invited panellist on Ethical and Social Issues of Nanotechnology, International Conference on Nanoscience and Nanotechnology, Brisbane Convention and Exhibition Centre, July 2006.
- Kyle. R. Nanotechnology: Changing Social Relations. presented at *The Governance of Science and Technology;* A Joint GovNet/CAPPE/ UNESCO Conference 9-10 August 2007, Australian National University.
- Kyle, R., Dodds. S. Processes for public deliberation on the ethics of enhancement technologies and bionics. Paper submitted to ICONN 2008.
- Kyle. R. Sounding out the self: Ethical implications of bionic devices. ACES Full Centre Workshop, Melbourne, St. Vincent's Institute for Medical Research; October 3-4 2007.

EQUIPMENT AND INFRASTRUCTURE

A detailed description of all ACES equipment, characterisation facilities, expertise and points of contact has been prepared. This "document" has been endorsed by the End Users Committee and the International Advisory Board and the facilities/expertise deemed as "world class" by the latter.

A LIEF proposal for NMR facilities was not lodged in 2007. However, a LIEF proposal to establish improved solar cell fabrication and characterisation facilities that involved both Monash and UoW researchers was successful.

GOVERNANCE

The End Users committee was established and met 3 times during 2007. A number of comments and recommendations were taken to the International Advisory Board meeting and are reflected in the IAB report.

INTELLECTUAL PROPERTY

A review of ACES IP was undertaken during 2007. A number of patents that can be combined to make a potentially commercially viable portfolio in the area of novel electromaterials has been identified and strengthened by lodging additional patents in the carbon nanotube and graphene areas.

EDUCATION AND OUTREACH

During 2007 ACES has worked closely with the Wollongong Science Centre participating in two public fora "Health Options in 2020" and "Energy Options".

ACES staff continue to interact strongly with undergraduates through summer research programs and B. Nanotechnology degree at University of Wollongong. ACES research has attracted significant TV, radio and print media interest during 2007 (see Appendix V).

Activity Plan 2008

RESEARCH PROGRAMS

The core experimental activities will focus on the Year 3 milestones given below. Milestones for other years (see Appendix I) will also be addressed where applicable.

P1: ELECTROMATERIALS

P1-1 Synthesis and Processing

SYNTHESIS OF NANO-ORGANIC MATERIALS

MILESTONE 1

Prepare porphyrins, oligothiophenes, ferrocenes and fullerenes for attachment to Inherently Conducting Polymers, Carbon Nanotubes and nano-inorganic materials for P2 and P3 (End Year 3).

MILESTONE 2

Prepare cell growth promoters, peptides and polyelectrolytes for P4 (End Year 3).

MILESTONE 3

Prepare functionalised Inherently Conducting Polymers and Carbon Nanotubes for P2 and P3 (End Year 3).

MILESTONE 4

Elucidate biomolecule – nanosized bioconjugate interactions (End Year 3).

MILESTONE 8

Prepare porphyrin-functionalised Au or ITO surfaces for photoelectrodes in P2 (End Year 3).

MILESTONE 10

Prepare ICP-coated inorganic nanostructures for P3 (End Year 3 then ongoing).

Refined milestone:

Prepare ICP-coated inorganic nanostructures for P2 and P3 (End Year 3)

MILESTONE 16

Develop and characterize highly conductive zwitterion based electrolytes (End Year 3).

MILESTONE 17

Prepare new functionalised nanoparticles for incorporation into gel electrolytes (End Year 3).

MILESTONE 18

Develop and characterise nanocomposite electrolytes containing functional fillers (End Year 3).

P1-3 Modelling

MILESTONE 24

Simulate model electromaterials, processes and devices (End Year 3).

P2: ENERGY CONVERSION

P2-1 Solar Energy Conversion

MILESTONE 26

Develop nanostructured photoelectrochemical solar cells with >5% efficiency (End Year 3).

P2-2 Electromechanical Actuators

MILESTONE 31

Develop artificial muscles with 5% strain at loads up to 10 MPa and strain rates of >10% sec^{-1} (End Year 3).

P2-3 Nanostructured Electroluminescent Materials

MILESTONE 33

Develop and demonstrate energy efficient nanostructured electroluminescent devices (End Year 3).

P3: ENERGY STORAGE

P3-1 All Solid-State Thin-Film Lithium-Ion Microbatteries

MILESTONE 35

Develop nanostructured materials for electrode in Li-ion rechargeable battery (End Year 3).

MILESTONE 36

Develop polymer electrolytes for advanced lithium-ion batteries (End Year 3).

MILESTONE 37

Investigate the capacity loss and rechargeability of thin film anodes (End Year 3).

P3-2 Advanced Metal Batteries

MILESTONE 40

Develop highly conductive nanocomposite electrolytes and electrodes for metal battery applications (End Year 3).

P3-3 Organic Batteries

MILESTONE 42

Develop an all-polymer battery with capacity of 80 $mA.h.g^{-1}$ using nanostructured materials from P1 (End Year 3).

MILESTONE 43

Develop an all-polymer capacitor with capacity of the order of 100 $F\ g^{-1}$ (End Year 3).

MILESTONE 44

Develop fabrication techniques for flexible membrane structures utilising these materials (End Year 3).

P4: BIONICS

P4-1 Nerve Cell Communications

P4-2 Bio-stability and Biocompatibility

MILESTONE 49

Utilise and refine fibre fabrication protocols (P1) that allow for production of micro-devices to control the direction of neurite outgrowth (End Year 3).

P5: ETHICS

P5-1 Biosystems, Electromaterials and Commodification of Human Health

MILESTONE 52

An understanding of the impact of commodification on the development of bionics and the clinical applications of bionics (End Early Year 3).

P5-2 "Bionic People"

MILESTONE 53

An understanding of the significance of bionics for self-identity and uses of the self: ethics and the self (End Year 3).

EDUCATION MILESTONES

MILESTONE 57

Full Development of community outreach programs at Monash and Wollongong Science Centres (End Year 3).

MILESTONES REVIEW

The Centre Executive will embark on a major review of Centre Milestones in 2008. A significant research platform has now been laid that will enable us to revise and update milestones as appropriate to ensure the maximum outputs are realised. This will also be an opportunity to refine or reposition the strategic goals for ACES to capitalise on new opportunities not foreseen at the time of our original submission.

The revised plans and associated milestones will receive input from our End Users Committee and be examined by our International Advisory Board during 2008.

EQUIPMENT

ACES (UoW) will acquire purpose built laboratories and associated instrumentation during 2008. The move to the Wollongong Innovation Campus will be a significant step in the development of this National Resource.

GOVERNANCE

We are fortunate to have the experience and wise counsel of Dr Bridget Ogilvie to provide guidance to us through our IAB in 2008.

We will review the composition of the End Users Committee and adjust as necessary to reflect the true breadth of end-users across the commercial, educational and government research sectors as well as in heightening community awareness.

Appendix 1

MILESTONES REPORT FOR THE ARC CENTRE OF EXCELLENCE FOR ELECTROMATERIALS SCIENCE

The following milestones relate to the core research programs of the ARC Centre of Excellence. Materials produced in the course of these activities are also utilised in "other" centre projects.

P1: ELECTROMATERIALS

P1-1 Synthesis and Processing

SYNTHESIS OF NANO-ORGANIC MATERIALS

MILESTONE 1

Prepare porphyrins, oligothiophenes, ferrocenes and fullerenes for attachment to Inherently Conducting Polymers, Carbon Nanotubes and nano-inorganic materials for P2 and P3 (End Year 3).

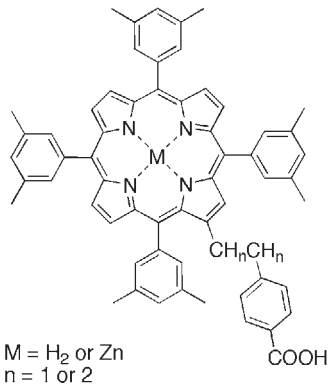
A wide variety of porphyrin dyes were supplied for attachment to titanium dioxide. Of particular note, are the benzoic acid porphyrins **1** and related porphyrin dimer **2** shown above. The preparation of functionalised thiophenes and terthiophenes and oligothiophenes for attachment to titanium dioxide and the preparation of polymers has continued.

Some examples of new materials are shown (**3**-**7**). A number of variants of **6** (R' = H) have been synthesised, especially where R contains a double or triple bond.

A number of 5,5-di and 5-monosubstituted fused fullerenylproline derivatives have been synthesized as well as 3 simpler fullerene ester derivatives. In the search for an electrochemically stable thiophene fullerene monomer, a new thiophene fullerene derivative **3** has been prepared.

MILESTONE OUTPUTS

- Facile synthesis of acetylene-substituted terthiophenes. Wagner, P., Partridge, A.C., Jolley, K.W., Officer, D.L. *Tetrahedron Letters,* 2007, 48, 6245-6248.
- Flip-type disorder in 3-substituted 2,2':5',2''-terthiophenes. Wagner, P., Officer, D.L., Kubicki, M. *Acta Crystallographica, Section C: Crystal Structure Communications,* 2007, C63(7), o400-o404.



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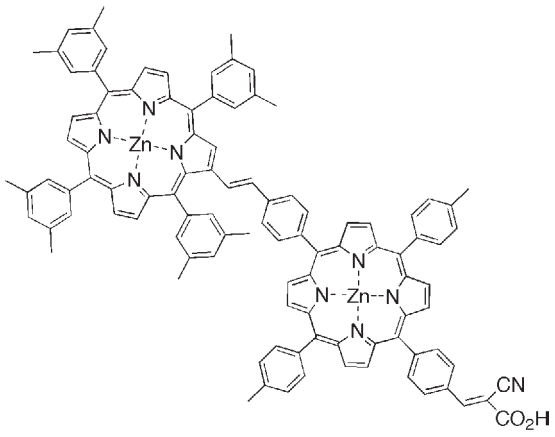

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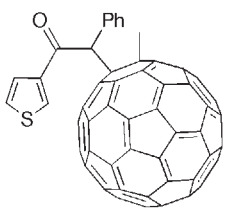

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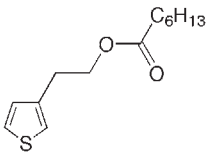

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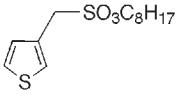

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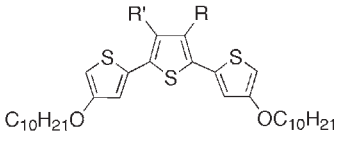

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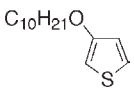

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- (Z)-2-Phenyl-3-(2,2':5',2''-terthiophen-3'-yl)acrylonitrile. Wagner, P., Officer, D.L., Kubicki, M. *Acta Crystallographica, Section E: Structure Reports Online,* 2007, E63(7), o3054-o3055.
- A Spectroscopic and Computational Study of the Neutral and Radical Cation Species of Conjugated Aryl-Substituted 2,5-Bis(2-thien-2-ylethenyl)thiophene-Based Oligomers. Earles, J.C., Gordon, K.C., Officer, D.L., Wagner, P. *Journal of Physical Chemistry A,* 2007, 111(30), 7171-7180.
- A modular procedure for the synthesis of functionalised ß-substituted terthiophene monomers for conducting polymer applications. Collis, G.E., Burrell, A.K., Blandford, E.J., Officer, D.L. *Tetrahedron,* 2007, 63(45), 11141-11152.
- Modulation of Electronic Properties in Neutral and Oxidized Oligothiophenes Substituted with Conjugated Polyaromatic Hydrocarbons. Clarke, T.M., Gordon, K.C., Wagner, P., Officer, D.L. *Journal of Physical Chemistry A,* 2007, 111(12), 2385-2397.

MILESTONE 2

Prepare cell growth promoters, peptides and polyelectrolytes for P4 (End Year 3).

It has been established that commercially available growth promoters (NT3 and BDNF) can be incorporated into (and released from) conducting polymers at clinically significant levels (see P4 milestone reports). Therefore, other composites containing biofunctional molecules were not synthesised.

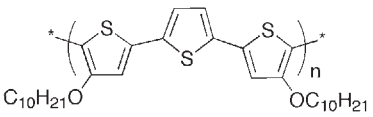
MILESTONE OUTPUTS

- Richardson, R.T., Thompson, B., Moulton, S., Newbold, C., Lum, M.G., Cameron, A., Kapsa, R., Clark, G., O'Leary, S., Wallace, G.G. *Biomaterials,* 2007, 28, 513.

MILESTONE 3

Prepare functionalised Inherently Conducting Polymers and Carbon Nanotubes for P2 and P3 (End Year 3).

Functionalised polyterthiophenes were prepared for solar cell, actuator and battery applications in P2 and P3. Thus, the soluble polyterthiophenes **8-10** were prepared for solar cell preparation. The styryl derivative **11**, previously shown to be useful for polymer batteries, was prepared and investigated as an actuator material. The electrochemically prepared indanedione polymer **12** was found to have a significant charge transfer band in the visible spectrum making it useful for solar cells. Consequently, the preparation of the soluble chemically prepared polymer was investigated.



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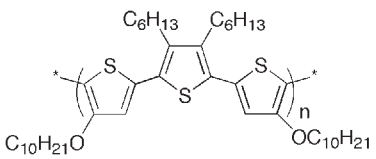

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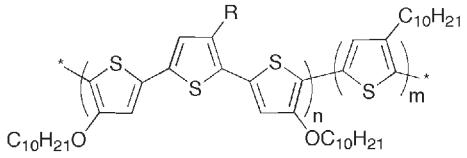

R = CO_2Me and $CO_2C_{10}H_{21}$

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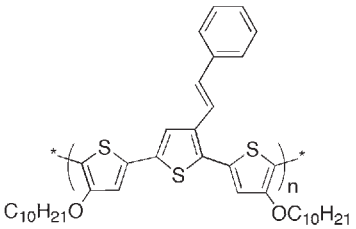

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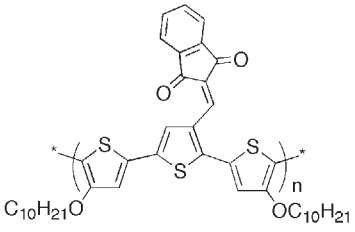


12

A variety of covalently and non-covalently functionalised CNTs have also been prepared or their preparation attempted. MWNTs with primary and secondary antibodies attached were produced and their functionalisation with Horse Radish Peroxidase and quantum dots successfully undertaken. This latter activity enabled the establishment of a new international collaboration with Prof. Richard O'Kennedy at Dublin City University (Ireland).

MILESTONE OUTPUTS

- Novel fullerene-functionalised poly(terthiophenes). Chen, J., Tsekouras, G., Officer, D.L., Wagner, P., Wang, C.Y., Too, C.O., Wallace, G.G. *Journal of Electroanalytical Chemistry,* 2007, 599(1), 79-84.
- Electrodeposition and characterisation of polypyrroles containing sulfonated carbon nanotubes. Lynam, C., Wallace, G.G., Officer, D.L. *Journal of Nanoscience and Nanotechnology,* 2007, 7, 3487-3494.

MILESTONE 4

Elucidate biomolecule – nanosized bioconjugate interactions (End Year 3).

Metal complexes of **L1** (Figure 1) have been explored as redox sensors for thymine derivatives and anions such as nitrate. The structures and electrochemical properties of a Zn(II)-thymine derivative and an unusual Cu(II) nitrate complex (top RHS of Figure 1) were determined. The instability of a precursor to **L1** has been studied with the finding that **1** and **2** are formed. A new ferrocenyl uracil Peptide Nucleic Acid (PNA) monomer, reported in late 2006 to bind effectively to the complementary nucleobases, is being incorporated into PNA sequences.

To examine biomolecule-bioconjugate interactions, a PNA-cyclen moiety was incorporated into a PNA sequence targeting the HIV-1 TAR element and binding affinities studied. Physicochemical studies of Ru(II) complexes incorporating a monocarboxylate bipyridine ligand were completed. One complex has been used to prepare PNA monomers (M1, M2), which are being incorporated into PNA sequences for use as biosensors. Ru(II) complexes of a new ligand, 4-carboxylic acid-2-pyridyl-2-pyrimidine, were prepared for use in PNA sequences.

MILESTONE OUTPUTS

- Recognition of thymine and related nucleosides by a Zn^{II}-cyclen complex bearing a ferrocenyl pendant. Gasser, G., Belousoff, M.J., Bond, A.M., Kosowski, Z., Spiccia, L. *Inorg. Chem.,* 2007, 46, 1665-1674.

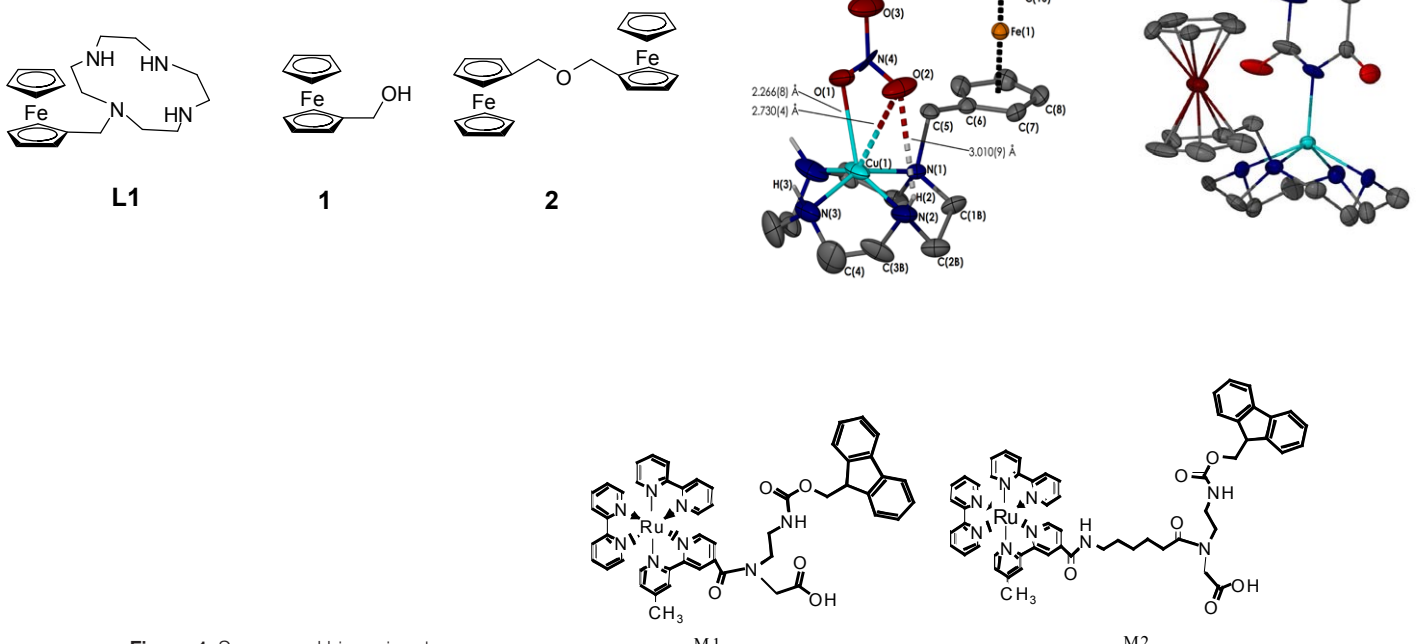


Figure 1. Some novel bioconjugates.

- Binding of nitrate to a Cu^{II}-cyclen complex bearing a ferrocenyl pendant: Synthesis, solid-state X-ray structure, and solution-phase electrochemical and spectrophotometric studies. Gasser, G., Belousoff, M.J., Bond, A.M., Spiccia, L. *Inorg. Chem.,* 2007, 46, 3876-3888.
- Products of hydrolysis of (ferrocenylmethyl)trimethyl-ammonium iodide: Synthesis of hydroxymethylferrocene and bis(ferrocenylmethyl)ether. Gasser, G., Fischmann, A.J., Forsyth, C.M., and Spiccia, L. *J. Organomet. Chem.,* 2007, 692, 3835-3840.
- Synthesis, structure and electrochemistry of ruthenium(II) complexes incorporating monocarboxylate bipyridine ligands. Nickita, N., Belousoff, M.J., Bhatt, A.I., Bond, A.M., Gasser, G., Spiccia, L. *Inorg. Chem.,* 2007, 46, 8638-8651.

MILESTONE 5

Supply of new materials to P2-P4 (Ongoing).

Functionalised polyterthiophenes and porphyrins continued to be prepared for solar cell, actuator and battery applications in P2 and P3.

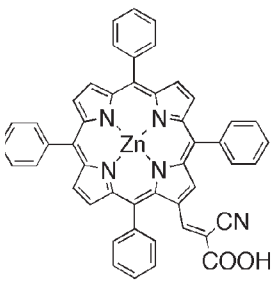
P2 – Energy conversion: A range of porphyrins **13-15** continue to be made for use in solar cells.

P3 – Energy storage: Polythiophenes **8** and **11** have been supplied to **P2** for plastic battery application, along with simpler materials such as poly(3-hexylthiophene).

P4 – Bionics: Poly(3-octylpyrrole) **16** and polythiophenes **8, 17**, **18** and poly(3-hexylthiophene) have been supplied to **P4** for cell growth experiments.

MILESTONE OUTPUTS

- Highly Efficient Porphyrin Sensitizers for Dye-Sensitized Solar Cells. Campbell, W. M., Jolley, K. W., Wagner, P., Wagner, K., Walsh, P. J., Gordon, K. C., Schmidt-Mende, L., Nazeeruddin, M. K., Wang, Q., Graetzel, M., Officer, D. L. *J. Phys. Chem. C* 2007, 111 (32), 11760-11762.



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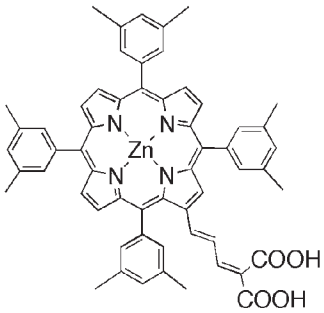

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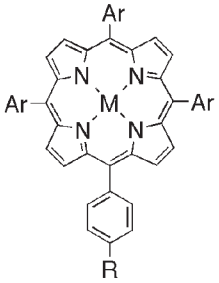
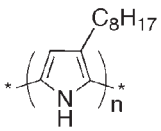


Ar = mesityl, tolyl, phenyl and p-octylphenyl.
R = CO_2H, $CHCHCNCO_2H$ or $CHCH(CO_2H)_2$.
M = H_2, Zn, Pt, Mg.

15



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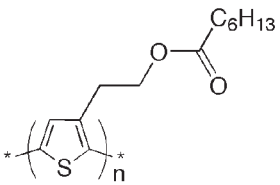

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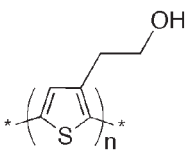


18

SYNTHESIS OF NANO-INORGANIC MATERIALS

MILESTONE 6

Prepare thin-film cathodes and anodes for P3 (End Year 2).

Co_3O_4 thin films were prepared by electrochemical deposition. Si thin films, porous Au thin films and $LiMn_2O_4$ thin films were prepared by pulsed laser deposition. Co_3O_4 thin films, Si thin films, and porous Au thin films **(Figure 2)** were used for anode materials in lithium rechargeable batteries and $LiMn_2O_4$ thin films were used as cathode materials.

A multilayer mesoporous Au film showed superior characteristics compared to an ordinary Au film, with a higher specific charge passed. $LiMn_2O_4$ thin film with the lowest deposition pulse rate exhibited the best electrochemical performance, retaining a charge capacity of 48 μAh cm^{-2} μm^{-1} beyond 100 cycles.

Initially the pulsed laser deposition (PLD) technique was proposed for the ARC Centre program. As the PLD method needs expensive equipment and strict conditions, the electrochemical deposition, a very convenient method to form nanostructured thin films with lower cost under the lower temperature, has been chosen to fabricate thin film Li-ion batteries. For example, the porous Co_3O_4 thin films were prepared by controlling the parameters of electrochemical deposition. This has provided new opportunities in this milestone and work has been ongoing beyond the end of Year 2.

MILESTONE OUTPUTS

Mesoporous gold as anode material for lithium-ion cells. Yuan, L., Liu, H. K., Maaroof, A., Konstantinov, K., Liu, J., Cortie, M. *J. New Materials for Electrochemical Systems,* 2007, 10, 95-99.

MILESTONE 7

Development of efficient ZnS nanoparticle synthesis (End Year 2).

The reverse micelle method has been developed for the synthesis of nanocrystals (with or without the presence of dopant) and core shell structures. The method development work has used CdS as a model system, however the approach is general to most metal sulfides. The synthesis takes place in small drops of water where nanoparticles of specific size and spherical shape can be created. The size of the micelles formed, as well as the nanoparticles, were found in this work to vary in the range of several nanometres (about 1-10 nm) by Dynamic Light Scattering. The synthesis of core shell structures with high stability and high quantum yield has also been developed. The quantum yield from these particles (>20%) is some of the highest ever observed from CdS. This synthesis development milestone is now completed and materials are being routinely made for device fabrication work in P2 and P3.

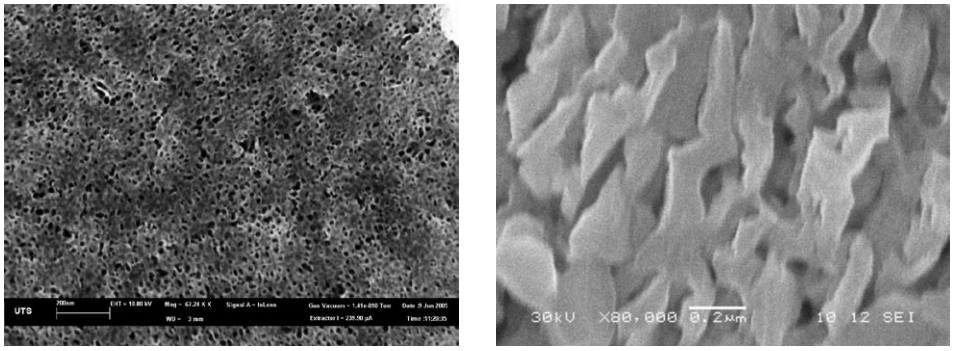


Figure 2. SEM images of mesoporous Au (a) single layer of 200 nm, (b) single layer of 100 nm.

MILESTONE 8

Prepare porphyrin-functionalised Au or ITO surfaces for photoelectrodes in P2 (End Year 3).

The functionalisation of ITO and Au surfaces undertaken in 2006 in this milestone led to the successful application for an ARC Discovery project on nanostructured solar cells. This new project involves the development of concepts and methods that could not be supported by ACES core funding. Therefore, no further work has been undertaken in the Centre on this area in 2007 and this milestone will no longer be part of the ACES research program.

MILESTONE OUTPUTS

- Self-Assembled Porphyrin-Fullerene Photovoltaic Electrodes: Towards Nanostructured Organic Solar Cells. Innis, P., Officer, D.L., Warrener, R.N. *Discovery Project DP0666707*, 2006-2008.

MILESTONE 9

Preparation of functionalised inorganic nanoparticles and nanofibres for P2 and P3 (End Year 4).

Families of hydrolysable silane derivatives **(Figure 3)** have been prepared and fully characterized. These compounds are being explored as potential iodide sources for use in dye sensitized solar cells (DSSCs) (P2).

A technique has been developed which allows functionalisation of silica-nanoparticles with silyl ammonium salts in order to introduce cationic groups whose charge is balanced by anions such as iodide **(Figure 4)**. These are intended for use as electrolytes in DSSCs.

MILESTONE OUTPUTS

- Novel nano-structured silica-based electrolytes containing quaternary ammonium iodide moieties. Cerneaux, S.A., Zakeeruddin, S.M., Pringle, J.M., Cheng, Y.-B., Grätzel, M., Spiccia, L. *Adv. Funct. Mater.,* 2007, 17, 3200-3206.

MILESTONE 10

Prepare ICP-coated inorganic nanostructures for P3 (End Year 3 then ongoing).

REFINED MILESTONE:

Prepare ICP-coated inorganic nanostructures for P2 and P3 (End Year 3)

A number of inorganic nanostructures (based on ITO or Pt) have been prepared using the inverse opal approach. However, attempts to prepare reasonable sized samples have to date been unsuccessful. The process is difficult to scale up. The structures are unfortunately brittle and with many imperfections. This activity will no longer be pursued.

MILESTONE OUTPUTS

- Preparation of platinum inverse opals using self-assembled templates and their application in methanol oxidation. Liu, Y., Chen, J., Misoska, V., Swiegers, G.F., Wallace, G.G. *Materials Letters,* 2007, 61, 2887-2890.

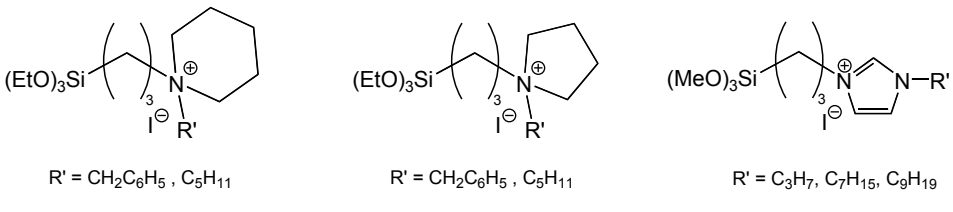


Figure 3. Hydrolysable silane derivatives

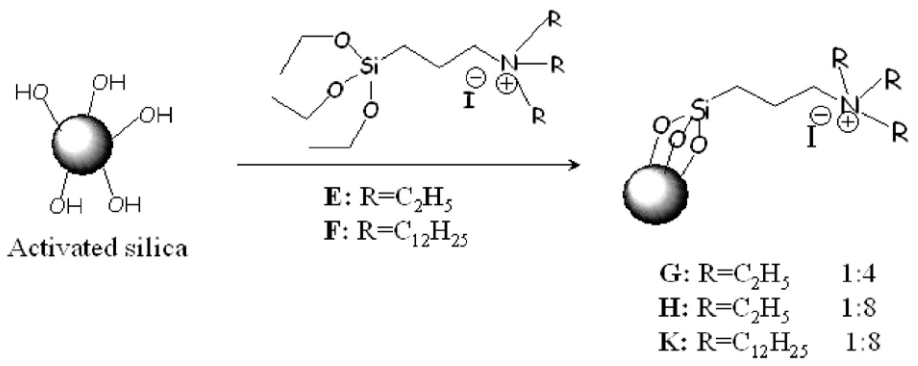


Figure 4. Functionalised silica-nanoparticles.

PROCESSING

MILESTONE 11

Establish wet-spinning fibre drawing facilities (End Year 1).

This milestone is complete and the facility has been extensively used to produce novel fibres. The range of fibres produced has been extended to include continuous, doped polypyrrole fibres, DNA-SWNT fibres, and a range of CNT-biofibres. The latter two developments have been accepted for publication in *Advanced Materials* and *Advanced Functional Materials*, respectively. We describe a novel solution spinning method used to produce highly conducting carbon nanotube (CNT) bio-fibres. In this process, carbon nanotubes are dispersed using a range of biomolecules (including DNA) and are used as spinning solutions.

The biomolecules are shown to be effective in dispersing the CNTs. Unlike previous reports in which a polymer binder is used in the coagulation bath, we show that these dispersions can be converted into fibres simply by altering the nature of the coagulation bath via pH control, use of a cross-linking agent or use of a biomolecule-precipitating solvent system. With comparable strength to most reported carbon nanotube fibres to date, these CNT bio-fibres demonstrated superior electrical conductivities. The DNA-CNT fibres also showed a stable electromechanical actuation.

MILESTONE OUTPUTS

- Production of polypyrrole fibres by wet spinning. Foroughi, J., Spinks, G.M., Wallace, G.G. and Whitten, P.G. *Synthetic Metals,* IN PRESS.
- DNA-wrapped single-walled carbon nanotube hybrid fibers for supercapacitors and artificial muscles, Shin, S.R., Lee, C.K., So, I., Jeon, J.-H., Kang, T.M., Kee, C., Kim, S.I., Spinks, G.M., Wallace, G.G., Kim, S.J. *Advanced Materials,* 2008, 20, 466-470.
- Carbon Nanotube Biofiber Formation in a Polymer-Free Coagulation Bath. Razal, J.M., Gilmore, K., Wallace, G.G. *Advanced Functional Materials*, 2008, 18, 61-66.

MILESTONE 12

Prepare aligned carbon nanotube samples for:

- Energy conversion: Aligned CNT-polythiophenes composite solar cells.
- Energy storage: Aligned CNT-PEDOT composites for batteries.
- Bionics: Aligned CNT-biopolymer composites for cell stimulation.

A number of approaches to functionalised carbon nanotubes have been investigated. These include covalent and non-covalent attachment. Covalent attachment results in severe compromises in both tube length (mechanical properties) and conductivity. Non-covalent attachment does not provide the degree of control in terms of loading or localisation of functional molecules. An alternative approach to functionalising carbon nanotube structures involves the use of a conducting polymer layer to interconnect the tubes. It is envisaged that functional molecules can be incorporated into this conducting polymer layer. Alternatively, conducting polymers containing functional molecules (e.g. the nerve growth factor NT3) have been coated onto the aligned CNTs. An enhanced rate of release from these structures has been demonstrated.

MILESTONE OUTPUTS

- Flexible, Aligned Carbon Nanotube/ Conducting Polymer Electrodes for a Lithium-Ion Battery. Chen, J., Liu, Y., Minett, A.I., Lynam, C., Wang, J., Wallace, G.G. *Chemistry of Materials* 2007, 19, 3595-3597.

MILESTONE 13

Establish sol-gel methods for self assembly (End Year 2).

In this work, the sol-gel process has been used to assemble alkylammonium iodide functionalities around silica nanoparticle templates. The reaction of activated silica with triethoxysilane alkylammonium iodides gives a new range of materials that are soluble in organic solvents and which can be used in the development of electrolytes for use in dye-sensitised solar cells (DSSCs). We now have a variety of hydrolysable alkoxysilane with alkylammonium iodide functionalities which can be hydrolysed to self assemble a variety of new sol-gel matrices for use as electrolytes in DSSCs in P2. This work will be reported on in due course.

MILESTONE 14

Supply of fabricated structures to P2-P4 (End Year 2 then ongoing).

A number of fibre structures as well as carbon nanotube-based electrode structures have been supplied.

FUNCTIONAL ELECTROLYTES

MILESTONE 15

Develop and characterize enhanced performance electrolytes including plastic and solid gel electrolytes (End Year 2).

Three key areas have continued to be developed under this milestone; plastic crystal electrolytes, polymer gel electrolytes and ionic liquids (ILs). Materials based on pyrrolidinium thiocyanate have been prepared and characterised using conductivity, solid state NMR and vibrational spectroscopy. The dimethyl pyrrolidinium thiocyanate material has a large solid-solid phase transition, presumably from ordered to plastic phase, at around 80°C which is accompanied by a step change in conductivity and a sudden narrowing of the proton NMR line width confirming cation diffusion. These materials are potential candidates for dye sensitized solar cell work in P2.

Work continues on characterising nanocomposite materials based on the methyl, ethyl pyrrolidinium bis(trifluorosulfonamide) plastic crystal with inorganic nanoparticles. The SiO_2 based systems have yielded the highest conductivities and lead to mechanically robust films. Solid state NMR, conductivity and thermal analysis have been used to probe the phase behaviour and transport in these materials. Thin films (less than 50 μm) were tested in a lithium metal cell and results indicate that they are excellent candidates for use as a solid state lithium thin film electrolyte. Ionic liquids, IL mixtures, and polymer gels (containing nanoparticles) have also been prepared and characterised as possible electrolytes in Mg batteries and lithium batteries.

The discovery work in this milestone activity is now largely complete and materials are being supplied for use as electrolytes in the work in Programs 2 and 3.

MILESTONE OUTPUTS

- Nanoparticle enhanced conductivity in organic ionic plastic crystals: Space charge versus strain induced defect mechanism. Shekibi, Y., Gray-Weale, A., MacFarlane, D.R., Hill, A.J., Forsyth, M. *Journal of Physical Chemistry C,* 2007, 111(30), 11463-11468.
- Rotational and translational mobility of a highly plastic salt: Dimethylpyrrolidinium thiocyanate. Grimsley M., MacFarlane, D.R., Forsyth M. *Solid State Ionics,* 2008, 178, 1798-1803.
- A new class of proton-conducting ionic plastic crystals based on organic cations and dihydrogen phosphate. Yoshizawa-Fujita, M., Fujita, K., Forsyth, M., MacFarlane, D. R. *Electrochemistry Communications,* 2007, 9, 1202-1205.
- N-methyl-N-alkylpyrrolidinium bis(perfluoroethylsulfonyl) amide ([NPf(2)](-)) and tris(trifluoromethanesulfonyl) methide ([CTf3](-)) salts: Synthesis and characterization. Johansson, K.M., Adebahr, J., Howlett, P.C., Forsyth, M., MacFarlane, D.R. *Australian Journal of Chemistry,* 2007, 60, 57-63.
- Plastic crystal behaviour in tetraethylammonium dicyanamide. Annat, G., Adebahr, J., McKinnon, I.R., MacFarlane, D.R., Forsyth, M. *Solid State Ionics,* 2007, 178, 1065-1071.

MILESTONE 16

Develop and characterize highly conductive zwitterion based electrolytes (End Year 3).

Zwitterion based electrolytes based on Ionic Liquids and polymer/nanocomposite gels have been prepared and characterised using conductivity, a.c. impedance and thermal analysis. The optimum compositions have been cycled in lithium symmetric cells showing a 100% improvement in the cycling and current densities achievable. Characterisation of these cells using EIS as well as XPS and solid state NMR of the lithium surface to examine the interface (SEI) following the completion of cycling indicates that the SEI layer is significantly thinner and more than a factor of 4 times less resistive. The zwitterion electrolyte appears to have a major role in a more favourable SEI.

MILESTONE OUTPUTS

- The effect of zwitterion on the Lithium SEI in ionic liquid electrolytes. Byrne, N., Howlett, P.C., MacFarlane, D.R., Smith, M.E., Howes, A., Hollenkamp, T., Forsyth, M. *J. Power Sources,* 2008, in press.
- Gel electrolytes based on lithium modified silica nano-particles. Sun, J., Bayley, P., MacFarlane, D. R., Forsyth, M. *Electrochimica Acta*, 2007, 52(24), 7083-7090.

MILESTONE 17

Prepare new functionalised nanoparticles for incorporation into gel electrolytes (End Year 3).

We have developed a novel nanocomposite polymer electrolyte containing silica nanoparticles grafted with iodide salts (Figure 5) and made attempts to fabricate an all-solid-state monolithic DSSC using the electrolyte. The influence of the silica nanoparticles grafted with iodine salts on the conductivity and the thermal behaviour of the polymer electrolyte was characterized by impedance spectroscopy and differential scanning calorimetry (DSC). The photovoltaic property of the all-solid-state monolithic DSSC with the electrolytes was also measured.

MILESTONE OUTPUTS

- Novel nano-structured silica-based electrolytes containing quaternary ammonium iodide moieties. Cerneaux, S.A., Zakeeruddin, S.M., Pringle, J.M., Cheng, Y.-B., Grätzel, M., Spiccia, L. *Adv. Funct. Mater.,* 2007*,* 17*,* 3200-3206.

MILESTONE 18

Develop and characterise nanocomposite electrolytes containing functional fillers (End Year 3).

Sulfonate functionalised silica nanoparticles with a lithium counterion have been incorporated into gel electrolytes and plastic crystal electrolytes. In the case of plastic crystal C_2mpyrTf_2N, we have seen an increase of ionic conductivity with increasing nanoparticle amount up to 20wt% although the conductivity increase is not as dramatic as with the pristine SiO_2 powder; possibly due to an increase in particle size upon functionalising. The SEM shows a relatively uniform dispersion of these particles in the plastic crystal and the mechanical properties of pellets made from these nanocomposites are significantly better than the pristine plastic crystal. Gel materials using the functionalised SiO_2 as a source of Li^+ have shown excellent lithium cycling in electrochemical measurements.

MILESTONE OUTPUTS

- Gel electrolytes based on lithium modified silica nano-particles. Sun, J., Bayley, P., MacFarlane, D.R. and Forsyth, M. *Electrochimica Acta*, 2007, 52(24), 7083-7090.
- Gel electrolytes based on lithium macro-anion salt. Sun, J., MacFarlane, D.R. and Forsyth, M. *Solid State Ionics*, 2007, 178, 785-791.

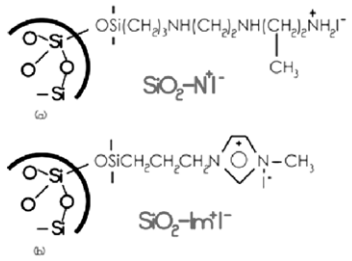


Figure 5 Functionalised nanoparticles

MILESTONE 19

Supply/refinement of electrolytes for P2-P4 (End Year 2 then ongoing).

For P2 requirements, see milestones 27 and 32.

For P3 requirements, see milestone 36.

P4 requirements – biocompatible electrolytes for bio batteries.

Polymer/Ionic liquid gel and plastic crystal materials based on (pyrrolidinium bistrifluoramide) materials have been supplied to P3 activities at both Monash and Wollongong nodes. Outputs from this work have been reported in P3 milestones.

Solid state polymer electrolytes and plastic crystal electrolytes have been supplied to the solar cell activities in P2 at Monash University. In addition, plastic crystal membrane materials have been supplied to Prof. Geoff Spinks for the actuator activities.

P1-2 CHARACTERISATION

MILESTONE 20

Establishment of co-ordinated characterisation users' network (End Year 2).

- A detailed report listing all equipment, location and nominated trainers has been compiled for ACES members (IPRI, ISEM, Monash, St Vincent's/ BEI). This document provides a brief description of the characterisation equipments' capabilities and uses.

MILESTONE OUTPUTS

Characterisation report is now available on the web **http://www.electromaterials.edu.au/resources/facilities.html**

MILESTONE 21

Dr Peter Innis (QEII Fellow) will coordinate and educate on the use of conventional characterisation tools such as SEM, AFM, NMR, UV-vis and electrochemical methods, as well as specialist in-situ techniques such as Electrochemical-Electron Spin Resonance, Electrochemical-Raman and Localised Electrochemical Impedance Spectroscopy (Ongoing).

A number of in-house training courses have been delivered (see Education Milestones 55-57). Centre staff also obtain training on specialised imaging techniques as part of a UoW arrangement with NanoMNRF (relaunched as The Australian Microscopy & Microanalysis Research Facility (AMMRF)). Funding has been sourced to provide new characterisation facilities for ACES to be housed at the UoW campus.

MILESTONE 22

Utilisation of novel characterisation tools in P1-P4 (Ongoing).

- New instrumentation has been purchased at UoW.
- A training program has been established for 2008.

MILESTONE 23

Characterisation of reactive metal interfaces to develop understanding of interfacial phenomena at electromaterials interfaces and in applications including corrosion, electrowinning and energy storage and conversion (Ongoing).

Lithium metal surfaces prepared on copper foils and exposed to ionic liquid and zwitterions based electrolytes were characterized using impedance spectroscopy, solid state NMR and XPS. These complimentary characterization techniques were able to provide some understanding as to the nature of the improved lithium cell performance in the zwitterions containing electrolyte (*J. Power Sources* accepted). These same characterisation techniques also continue to be applied to magnesium alloy surfaces to characterize the surface formed on these alloys from novel ionic liquids prepared in separate ARC projects.

Aluminium alloy 2024 and 7075 surfaces that have been protected against corrosive environments via new rare earth corrosion inhibitors, supplied by our chemistry colleagues from the Centre for Green Chemistry, have also been characterised using the suite of techniques available within ACES. This has facilitated an understanding of the inhibition mechanism on these alloys.

Additional complimentary characterization methods have been developed to further determine the nature of the surface film on metal alloys; specifically profilometry methods and a new type of electrochemical cell (pipette cells) for EIS measurement of in-situ film evolution. These will be applied to a number of metal surfaces including Mg and Al alloys.

MILESTONE OUTPUTS

- The effect of zwitterion on the Lithium SEI in ionic liquid electrolytes. Byrne, N., Howlett, P.C., Macfarlane, D.R., Smith, M.E., Howes, A., Hollenkamp, T., Forsyth, M. *J. Power Sources,* 2008, in press.
- Inhibition of Corrosion on AA2024-T3 by New Environmentally Friendly Rare Earth Organophosphate Compounds (invited paper). Forsyth M., Markley T., Ho D., Deacon G.B., Junk P., Hinton B., Hughes A. *Corrosion*, 2008, in press.
- Influence of praseodymium - Synergistic corrosion inhibition in mixed rare-earth diphenyl phosphate systems. Markley, T.A., Hughes, A.E., Ang, T.C., Deacon, G.B., Junk, P., Forsyth, M., *Electrochemical and Solid State Letters,* 2007, 10(12), C72-C75.
- Passivation of reactive metals using novel chemical treatments. Forsyth, M., Lead Paper 6 (invited), *Proceedings of 'Corrosion & Prevention 2007; Sydney November 2007.*
- An investigation of a phosphinate-based ionic liquid for corrosion protection of magnesium alloy AZ31. Howlett, P.C., Zhang, S., MacFarlane, D.R., Forsyth, M. *Australian Journal of Chemistry,* 2007, 60, 43-46.
- Exploring corrosion protection of Mg via ionic liquid pretreatment. Birbilis, N., Howlett, P.C., MacFarlane, D.R., Forsyth, M. *Surface & Coatings Technology,* 2007, 201, 4496-4504.

P1-3 MODELLING

MILESTONE 24

Simulate model electromaterials, processes and devices (End Year 3).

Modelling of electromaterials systems has continued to concentrate on actuator systems as a complex example involving both electrochemical and mechanical processes. The coupling of actuators with mechanical sensors has been shown to be useful for feedback control of the actuator. In addition, extended mechanical modelling of bending-type actuators has been completed, which show the effects of actuator dimensions on performance. Finally, the application of bending actuators for propulsion of a fish-like robot has also been modelled and published. Current work is focussing on the fundamental electrochemical and mass-transfer processes that are fundamental to the actuation response.

- Feedback control of tri-layer polymer actuators to improve their positioning ability. Yao, Q., Alici, G., Spinks, G.M. *Sensors & Actuators A*, 2007, in press.
- Tri-layer polymer actuators with variable dimensions. Minato, R., Alici, G., McGovern, S.T., Spinks, G.M. Proc. of the SPIE 14th International Symposium on Smart Structures and Materials, and Nondestructive Evaluation and Health Monitoring, pp., Vol. 6524--57, San Diego, USA, March 2007.
- A Scalable Model for Trilayer Conjugated Polymer Actuators and Its Experimental Validation. Fang, Y., Tan, X., Shen Y., Xi, N., Alici, G. *Materials Science and Engineering C - Biomimetic and Supramolecular Systems*, 2007, in press.
- Robust adaptive control of conjugated polymer actuators. Fang, Y., Tan, X., Alici, G. *IEEE Transactions on Control Systems Technology*, 2007, in press.
- Establishment of a biomimetic device based on tri-layer polymer actuators propulsion fins. Alici, G., Spinks, G.M., Huynh, N.N., Sarmadi, L. and Minato, R. *Bioinspir. Biomim*, 2007, 2, S18-S30.

MILESTONE 25

Integrate advanced characterisation and theory for material development (End Year 4).

Raman and NMR experiments along with ab-initio structure calculations have been conducted in order to investigate the interactions between the species present in ionic liquid media and to develop an understanding of how these species impact on applications including electrowinning of metals such as aluminium and lithium ion transport in battery applications.

MILESTONE OUTPUTS

- Towards a better understanding of ‘delocalized charge’ in ionic liquid anions. Izgorodina, E.I., Forsyth, M., et al. *Australian Journal of Chemistry,* 2007, 60(1), 15-20.

P2: ENERGY CONVERSION

P2-1 SOLAR ENERGY CONVERSION

MILESTONE 26

Develop nanostructured photoelectrochemical solar cells with >5% efficiency (End Year 3).

In collaboration with Professor Michael Graetzel at EPFL, Lausanne, a world record of over 7% efficiency was reported for porphyrin-sensitised titanium dioxide solar cells. Similar porphyrins also attained >4% efficiencies in solid state dye sensitised solar cells (DSSCs). A variety of other porphyrins synthesised in P1-1 were incorporated into solar cells and a new mechanism of light harvesting demonstrated. A DSSC containing a porphyrin dimer has shown an enhanced efficiency for the first time (>3%). The effect of varying the porphyrin dyes has also been probed using impedance spectroscopy for the first time.

In the development of new electrolytes, collaboration with Professor Graetzel (funded by an ARC Linkage International Grant) was ongoing. Dr Naomi Lewcenko visited Lausanne where she tested $[(RO)_3Si(CH_2)_nX^+]I^-$ (X^+ = ammonium, piperidinium, pyrrolidinium and imidazolium groups). DSSC efficiencies of 7-8.5% were achieved at low light intensity (0.1 sun) with some of the pyrrolidinium- and piperidinium-based electrolytes (Figure 3, page 66).

MILESTONE OUTPUTS

- Highly Efficient Porphyrin Sensitizers for Dye-Sensitized Solar Cells. Campbell, W.M., Jolley, K.W., Wagner, P., Wagner, K., Walsh, P.J., Gordon, K.C., Schmidt-Mende, L., Nazeeruddin, M.K., Wang, Q., Graetzel, M., Officer, D.L. *Journal of Physical Chemistry C,* 2007, 111(32), 11760-11762.
- Understanding and Improving Solid-State Polymer/C60-Fullerene Bulk-Heterojunction Solar Cells Using Ternary Porphyrin Blends. Dastoor, P.C., McNeill, C.R., Frohne, H., Foster, C.J., Dean, B., Fell, C.J., Belcher, W.J., Campbell, W.M., Officer, D.L., Blake, I.M., Thordarson, P., Crossley, M.J., Hush, N.S., Reimers, J.R. *Journal of Physical Chemistry C,* 2007, 111(42), 15415-15426.
- Overall Program Output: Formation and funding of the Victorian Organic Solar Cell consortium with University of Melbourne, CSIRO and industry. Funded by Victorian Government ($6M 2007-2010) and institutional funds ($6M).

MILESTONE 27

Develop nanostructured solid state polymer (electrolyte) solar cells with >4% efficiency (End Year 4).

REFINED TO:

Develop nanostructured solid state solar cells with >4% efficiency (End Year 4).

Polymer DSSCs generally suffer from reduced energy conversion efficiencies compared to DSSCs employing liquid, solvent-based electrolytes. The reduced performance is due to a reduction in ionic mobility in the solid phase, as well as fabrication issues, related to the defect-free infiltration of a nanostructured electrode with a solid electrolyte matrix. We were able to show that the latter has a major impact on the energy conversion efficiency of polymer solar cells. A new vacuum-based fabrication method was developed in our Centre allowing to increase the conversion-efficiency of polyethylene oxide based polymer solar cells from 1.33 to 3.54 %. At the same time we were able to quantify the pore-filling of polymer electrolyte solar cells based on TEM and EDS analysis.

MILESTONE OUTPUTS

- Increased Nanopore Filling: Effect on monolithic all-solid-state dye-sensitized solar cells. Han, H., Bach U., Cheng Y., Caruso R., *Applied Physics Letters,* 2007, 90, article 213510.

MILESTONE 28

Develop nanostructured self-assembled photoanodes for integration into both solar conversion cells (End Year 5).

THIS MILESTONE WAS MODIFIED IN 2006 TO:

Develop nanostructured photocathodes for integration into tandem solar cells

(End Year 5).

We have developed a novel fabrication method for the preparation of mesoporous NiO films based on preformed NiO nanopowders. Critical properties such as pore-size distribution, crystallinity and internal surface area of the resulting NiO films were controlled through the sintering process and optimized for their application as dye-sensitised photocathodes. Optimized devices based on a coumarin sensitizer yielded short-circuit currents of 2.13 mA/cm^2, compared to 4.1 mA/cm^2 reported for the same sensitizer when applied in a conventional TiO_2 photoanode. This is the highest value reported so far for dye-sensitized NiO solar cells.

P2-2 ELECTROMECHANICAL ACTUATORS

MILESTONE 29

Establish basic mechanisms of gel adhesion to electrodes (End Year 1).

The work related to this milestone has been completed and is mainly concerned with developing an understanding of the adhesion of ionic gels to charged and uncharged substrates. Both anionic and cationic gels have been synthesized and their adhesion to each other and to oppositely charged substrates has been measured. The adhesion is found to be highly dependent on the pH and the ionic strength of the environment, as it is caused by 'counter-ion evaporation', that is the free energy, mainly entropy, change when a polymeric counter-ion is exchanged for a small molecule counter-ion, releasing the small molecule counter-ion into the solution.

At neutral pH and at low ionic strength the adhesion is strong enough to cause cohesive failure within the (untoughened) gels. As gels with high adhesion need also to be tough (as do gels that are useful as actuators), it has proved essential to gain an understanding of the techniques for making tough gels. To this end, a collaboration has been initiated with Professor J. P. Gong of Hokkaido University whose group has developed tough, double network gels. A theory of the mechanism by which the existence of the two networks toughens these double network gels has been developed and submitted for publication.

MILESTONE OUTPUTS

- A model of the fracture of double network gels. Brown, H. R. *Macromolecules*, 2007, 40, 3815-8.
- A Novel Hydrogel with High Mechanical Strength: Macromolecular Microsphere Composite Hydrogel. Huang, T., Xu, H., Jiao, K., Zhu, L., Brown, H.R., Wang, H. *Advanced Materials*, 2007, 19, 1622-26.

MILESTONE 30

Develop phenomenological models of ICPs and gel actuation under low voltage electrochemical stimulus, taking into account the influence of ion movements, osmotic effects, chain conformation changes and changing mechanical properties (End Year 2).

Studies relating to understanding the mechanisms of actuation occurring in ICPs and gel actuators have focused on sensors (reverse actuation) and new materials development. We discovered that ICP actuators could operate in reverse to produce a mechanical sensor. We were able to propose a mechanism for the sensor output and quantitatively estimate the magnitude of the voltage or current produced. This work has been accepted for publication in *Advanced Functional Materials.* Further work has continued into the understanding of the change in elastic modulus of ICPs during redox cycling, as this process affects the actuation performance.

Finally, a thorough review of the fundamental mechanisms of actuation in ICPs has been initiated and a review paper prepared for publication. An additional review of CNT actuation mechanisms and devices will also be published in early 2008. This milestone is completed and the new knowledge regarding actuator mechanisms will be used to produce large strain, higher strength ICPs and gel actuators in future ACES research.

MILESTONE OUTPUTS

Soft Mechanical Sensors Through Reverse Actuation in Polypyrrole. Wu, Y., Alici, G., Madden, J.D.W., Spinks, G.M. and Wallace, G.G. ***Advanced Functional Materials,*** 2007, 17, 3216-3222.

MILESTONE 31

Develop artificial muscles with 5% strain at loads up to 10 MPa and strain rates of >10% sec^{-1} (End Year 3).

The improvement in actuator performance comes from the introduction of new materials and builds on the fundamental work reported under Milestone 30. Novel materials developed recently include a combined hydrogel/ICP/SWNT material that showed both electrochemical and pH-induced actuation. In addition, we have shown that novel solution processable polythiophenes generate large actuation (>10% strain). Novel processing techniques have also led to improvements in actuation performance.

For example, flash welded polyaniline nanofibres showed very fast actuation in response to chemical vapours. This work has been accepted for publication in *Advanced Materials.* In addition, electrospun hydrogel fibres using the protein ferritin have been developed that also show rapid (and stable) pH induced actuation. This work will also be submitted for publication. The combined expertise available in the Centre relating to materials synthesis (eg. solution processable polythiophenes) and materials processing (eg. electrospinning) has enabled significant advances in actuator performance during 2007. In particular, the ability to construct nano-structured films has significantly improved the speed of actuation.

MILESTONE OUTPUTS

- A novel "dual mode" actuation in chitosan/polyaniline/carbon nanotube fibers. Spinks, G.M., Shin, S.R., Wallace, G.G., Whitten, P.G., Kim, I.Y., Kim, S.I. and Kim, S.J. *Sensors & Actuators: B. Chemical*, 2007,121, 616-621.
- Electrochemical actuation properties of a novel solution-processable polythiophene. Wu, Y., Ballantyne, A.M., Wagner, P., Zhou, D., Spinks, G.M., Officer, D., Wallace, G.G. *Electrochimica Acta,* 2007, 53, 1830-1836.
- Actuation behaviour of polyaniline films and tubes prepared by the phase inversion technique. Xi, B., Truong, V.-T., Mottaghitalab, V., Whitten, P.G., Spinks, G.M., Wallace, G.G. *Smart Materials and Structures,* 2007, 16, 1549-1554.

MILESTONE 32

Develop electrochemical pneumatic actuators using nanostructured electrodes and electrolytes (End Year 5).

Further evaluation of potential electrolytes has been conducted, with an assessment completed of the pressure developed in a closed electrochemical cell. Reversible pressure cycles could be produced to 0.5 Bar, although some degradation of the electrode occurred on repeated cycling. Efficiencies of the process were low.

We have now verified that the original pneumatic actuation observed is peculiar to laser ablated tubes and even then depends on quality of batch. Extensive studies have not identified the physical reason for actuating vs non-actuating structures. It is recommended that this project no longer be pursued with the ARC Centre.

Work on alternative pneumatic actuation possibilities involving CNTs is ongoing as part of a collaborative project with DSTO.

P2-3 NANOSTRUCTURED ELECTROLUMINESCENT MATERIALS

MILESTONE 33

Develop and demonstrate energy efficient nanostructured electroluminescent devices (End Year 3).

Two types of device have been developed in this work. The structure of the *alternating current* (AC) thin film electroluminescent device that has been constructed in this work is shown in **Figure 6.** The figure also shows thin film of CdS and this covered with barium titanate.

Figure 7 shows the typical structure of a *direct current* (DC) powder electroluminescent device that has been used in this work. The phosphor here is cadmium sulfide doped with manganese semiconductor. Current is sustained by injection of electrons via tunnelling from the negatively charged metal cathode.

The fluorescence properties of optically "switchable" materials have also been investigated in collaboration with Prof Dermot Diamond and coworkers from Dublin City University. The potential to optically switch their electrochemical properties is under investigation as part of this work.

MILESTONE OUTPUTS

Photo- and Thermo-chromic Properties of Benzospiropyran in Ionic Liquids Containing the $[NTf_2]^-$ Anion. Byrne, R., Forsyth, M., MacFarlane D.R., Fraser K., Diamond, D. *J Phys Chem.,* 2008, in press.

MILESTONE 34

Optimise materials in nanostructured electroluminescent devices (End Year 5).

Work has not yet begun in this area.

Figure 6. The AC device.

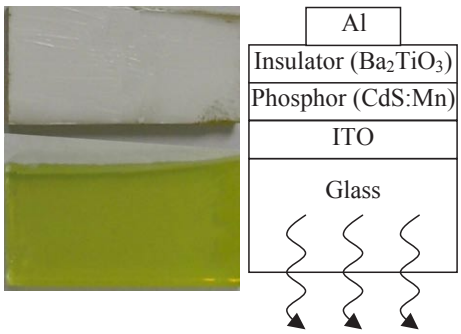
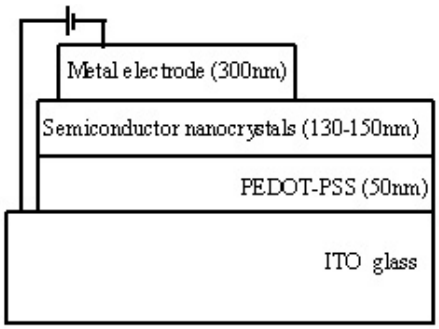


Figure 7. The DC device.



P3: ENERGY STORAGE

P3-1 ALL SOLID-STATE THIN-FILM LITHIUM-ION MICROBATTERIES

MILESTONE 35

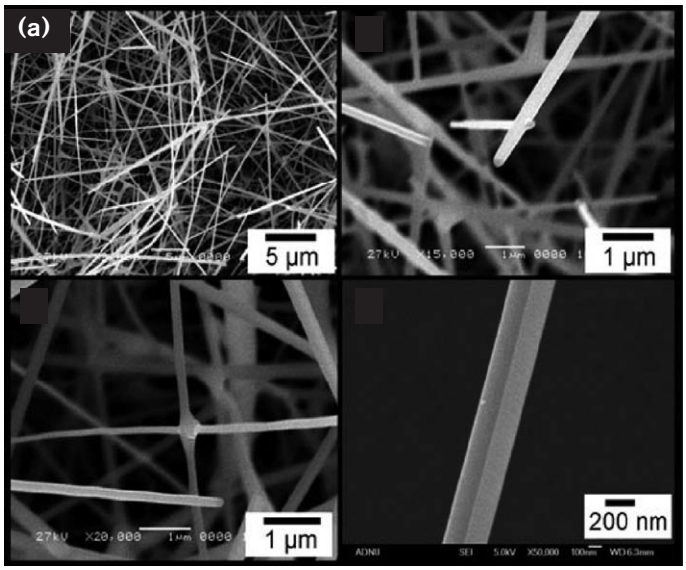
Develop nanostructured materials for electrode in Li-ion rechargeable battery (End Year 3).

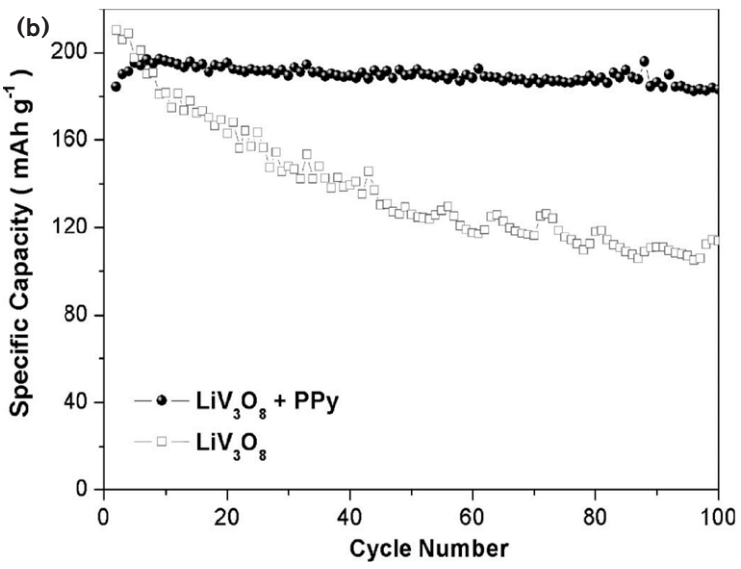
SnO_2 nanowires, nanostructured SnSb/CNTs, nano-silicon/polypyrrole composite, one-dimensional (1D) nanostructures of vanadium pentoxide (V_2O_5), and PPy-coated LiV_3O_8 composites were investigated. SnO_2 nanowires showed higher initial coulombic efficiency and an improved cyclic retention than that of SnO_2 powder and SnO_2 nanowires produced by Au-assisted growth. Nanostructured SnSb/CNTs show higher reversible capacity and higher coulombic efficiency than CNTs. The cycling stability of Si/PPy electrodes is significantly improved compared to the bare Si anodes. The electrochemical performance of LiV_3O_8–PPy composite is significantly enhanced, with a specific capacity of 183 mAh/g retained after 100 cycles **(Figure 8).**

MILESTONE OUTPUTS

- Novel nano-silicon/polypyrrole composites for lithium storage. Chew, S.Y, Guo, Z.P., Wang, J.Z., Chen, J., Munroe, P., Ng, S.H., Zhao, L., Liu, H.K. *Electrochemistry Communications,* 2007, 9, 941-946.
- Preparation and Electrochemical Properties of SnO_2 Nanowires for Application in Lithium-Ion Batteries. Park, M., Wang, G., Kang, Y., Wexler, D., Dou, S. X. and Liu, H.K. *Angewandte Chemie,* 2007, 46, 750-753.
- Characterization of Nanosize Molybdenum Trisulfide for Lithium Batteries and MoS_3 Structure Confirmation via Electrochemistry. Wang, J.Z., Ng, S.H., Chew, S.Y., Wexler, D., Wang, G.X., Liu, H.K. *Electrochemical and Solid-State Letters,* 2007**,** 10, A204.
- Nanostructured SnSb/carbon nanotube composites synthesized by reductive precipitation for lithium ion batteries. Park, M.S., Needham, S.A., Wang, G.X., Kang, Y.M., Park, J.S., Dou, S.X., Liu, H.K. *Chemistry of Materials,* 2007**,** 19(10), 2406-2410.
- Low temperature synthesis of Polypyrrole-coated LiV_3O_8 composite with enhanced electrochemical properties. Chew, S.Y., Feng, C., Ng, S.H., Wang, J.Z., Guo, Z.P., Liu, H.K. *Journal of The Electrochemical Society,* 2007**,** 154(7) A633-A637.
- Synthesis and electrochemical properties of V_2O_5 nanostructures prepared via a precipitation process for lithium-ion battery cathodes. Ng, S.H., Chew, S.Y., Wang, J.Z., Wexler, D., Tournayre, Y., Konstantinov, K., Liu, H.K. *Journal of Power Sources* 2007, 74 (2), 1032-1035.
- Synthesis and characterization of SnO_2-polypyrrole composite for lithium-ion battery. Yuan, L., Wang, J.Z., Chew, S.Y., Chen, J., Guo, Z.P., Zhao, L., Konstantinov, K., Liu, H.K. *Journal of Power Sources,* 2007, 174(2), 1183-1187.

Figure 8 (a) The microstructure of self-catalysis-grown SnO_2 nanowires. (b) Cycle life of bare LiV_3O_8 and LiV_3O_8–PPy composite.





MILESTONE 36

Develop polymer electrolytes for advanced lithium-ion batteries (End Year 3).

Polymer electrolyte materials based on a composite of a polymer matrix and an ionic liquid plasticising phase have been developed. These produce tough, free standing films that can be used to manufacture a lithium battery without the need for a separator. These have been shown to work extremely well with the LiV_3O_8-polypyrrole cathodes that have been developed in other parts of the ACES projects. Discharge capacity provided by the solid polymer electrolyte cathode combination is higher than exhibited by a standard liquid electrolyte with this cathode. Extended battery testing is underway.

MILESTONE OUTPUTS

- Lithium Polymer Battery Based on an Ionic Liquid Polymer Electrolyte Composite. Chew, S.Y., Liu, H., Sun, J., Forsyth, M., MacFarlane, D.R. *submitted to J Power Sources.*

MILESTONE 37

Investigate the capacity loss and rechargeability of thin film anodes (End Year 3).

The multilayer mesoporous Au electrode demonstrated a significantly better electrochemical cyclability than the other types tested. The capacity decay of all types of electrode is a problem shared with many other metallic alloy systems. The fading of the capacity may be caused by two reactions: (1) insertion of Li atoms leads to significant volume expansion of host structure, especially in the beginning few cycles, which can cause cracking and loss of electrical contact. However, removal of lithium from the Li_xAu particles does not affect the size of the expanded particles very much. So the discharge capacities of the electrodes can remain almost constant in subsequent cycles. (2) The formation of a passivating film, an electrically insulating layer on the battery electrodes also known as the solid electrolyte interphase (SEI) film, might also be affecting the capacity. When the thickness of SEI layer increases, the ionic impedance of the SEI increases. Since the lithium insertion process occurs on an electrode covered with the SEI, the characteristics of lithiation/delithiation, and stability of the interface are affected.

MILESTONE OUTPUTS

- Mesoporous gold as anode material for lithium-ion cells. Yuan, L., Liu, H.K., Maaroof, A., Konstantinov, K., Liu, J., Cortie, M. *J. New Materials for Electrochemical Systems,* 2007, 10, 95-99.
- Phase-controlled Si/Cu-Carbon composite as an anode material for Li ion secondary battery. Kang, Y.M., Park, M.S., Lee, J.Y., Liu, H.K. *Carbon,* 2007**,** 45(10),1928-1933.
- Spray-pyrolyzed silicon/disordered carbon nanocomposites for lithium-ion battery anodes. Ng, S.H., Wang, J.Z., Konstantinov, K., Wexler, D., Chew, S.Y., Guo, Z.P., Liu, H.K. *Journal of Power Sources,* 2007, 174 (2), 823-827.
- Amorphous carbon-coated silicon nanocomposites: A low temperature synthesis via spray pyrolysis, and their application as high capacity anodes for Li-ion batteries. Ng, S.H., Wang, J.Z, Wexler, D., Chew, S.Y., Liu, H.K. *The Journal of Physical Chemistry C,* 2007, 111, 11131-11138.
- Polyol-mediated synthesis of ultrafine tin oxide nanoparticles for reversible Li-ion storage. Ng, S., dos Santos, D., Chew, S., Wexler, D., Wang, J., Dou, S. X. and Liu, H.K. *Electrochemistry Communications,* 2007**,** 9, 915-919.
- Mesoporous organo-silica nanoarray for energy storage media. Park, M.S, Wang, G.X., Kim, S.Y., Kang, Y.M., Liu, H.K., Dou, S.X. *Electrochem. Commun.,* 2007**,** 9, 71-75.

MILESTONE 38

Develop chemically stable and structurally stable thin film cathodes (End Year 4).

A series of $LiMn_2O_4$ thin films on either Si (100) or stainless steel substrate were successfully prepared via PLD and were characterized physically by XRD, RBS, ERDA, SEM, AFM, Raman and by CV and charge/discharge tests. The effect of the type of substrates used for deposition and film thickness on the electrochemical performance of the $LiMn_2O_4$ thin films, especially on their interfacial properties were also thoroughly investigated. $LiMn_2O_4$ thin film with lowest deposition pulse rate (or thinnest film) exhibited the best electrochemical performance beyond 100 cycles. The specific capacity decreased as the current density increased. The as-deposited $LiMn_2O_4$ thin film electrode demonstrated good rate capabilities, even up to the 32C rate.

MILESTONE OUTPUTS

- The impact of nanomaterials on Li-ion rechargeable batteries. Liu, H.K., Wang, G.X., Guo, Z.P., Wang, J.Z., Konstantinov, K.*, J. New Materials for Electrochemical Systems*, 2007**,** 10, 101-104.
- In-situ fabrication and characterization of nanostructured Mn_3O_4 powders for electronic and electrochemical applications. Konstantinov, K., Tournayre, Y., Liu, H.K. *Materials Letters,* 2007**,** 61(14-15) 3189-3192.
- Nanostructured Nickel Sulfide Synthesized via a Polyol Route as a Cathode Material for the Rechargeable Lithium Battery. Wang, J.Z., Chew, S.Y., Wexler, D., Wang, G.X., Ng, S.H., Zhong, S., Liu, H.K. *Electrochem. Commun.,* 2007, 9(8), 1877-1880.
- Nanostructured materials for electrodes in lithium-ion batteries, Ng, S.H., University of Wollongong, PhD thesis (2007).

MILESTONE 39

Develop long life, high energy density, all solid-state thin-film Li-ion microbatteries (End Year 5).

Work on this milestone will commence in years 4 and 5 of the program; building on the outputs of Milestones 35–38 above.

P3-2 ADVANCED METAL BATTERIES

MILESTONE 40

Develop highly conductive nanocomposite electrolytes and electrodes for metal battery applications (End Year 3).

Work in this area has focussed on two different metal-anode battery types:

(i) Lithium metal based systems for high energy density batteries for printable devices and bionic devices. This work has focused on electrolyte combinations that produce a stable lithium interface and on cathode materials that are stable against the electrolyte. A unique cathode nano-composite material has been developed and tested. Results show high capacity and stable cycling.

(ii) Magnesium batteries for implantable bionic device use. These may be in the format of directly driving a controlled release cathode being developed in Program 4 or being a stand-alone battery to drive the device. The battery should be highly biocompatible and one ultimate goal is to have a device which is biodegradable. Drawing on the electrolyte work in Program 1, the magnesium battery effort has produced a working device which is capable of delivering up to 400 $\mu A/cm^2$. Testing under various discharge conditions is continuing.

MILESTONE OUTPUTS

- Magnesium Battery. Winther-Jensen, B., MacFarlane, D.R. and Forsyth, M. *Aust Provisional Patent Application* filed March 1, 2007.
- Ionic liquid-based rechargeable lithium metal-polymer cells assembled with Polyaniline/Carbon nanotube composite cathode. Sivakkumar, S.R., MacFarlane D.R., Forsyth M., Kim D.W. *J Electrochem. Soc,* 2007, 154(9), A834-A838.

MILESTONE 41

Develop an understanding of the interfacial phenomena at the electrode surfaces and use this to develop optimal performance in operational batteries (End Year 5).

Work on this Milestone will begin in years 4 and 5 of the program, building on Milestone 40.

P3-3 ORGANIC BATTERIES

MILESTONE 42

Develop an all-polymer battery with capacity of 80 $mA.h.g^{-1}$ using nanostructured materials from P1 (End Year 3).

A number of all polymer batteries have been constructed. The best reproducible capacity achieved to date utilises a polypyrrole cathode and polyhexythiophene anode; capacities of the order of 45 mAh/g were obtained.

Preliminary results that use polypyrrole with another conducting polymer as dopant (a sulphonated polyaniline) indicate that much higher capacities (in excess of 100 mAh/g) can be obtained. However, stability to cycling and reproducibility in battery fabrication are lacking.

MILESTONE OUTPUTS

- Polyaniline and polyaniline-carbon nanotube composite fibres as battery materials in ionic liquid electrolyte. Wang, C.Y., Mottaghitalab, V., Too, C.O., Spinks, G.M., Wallace, G.G. *Journal of Power Sources,* 2007, 163, 1105-1109.
- Flexible, Aligned Carbon Nanotube/ Conducting Polymer Electrodes for a Lithion-Ion Battery. Chen, J., Liu, Y., Minett, A.I., Lynam, C., Wang, J., Wallace, G.G. *Chemistry of Materials,* 2007, 19, 3595-3597.
- Conducting polymers with fibrillar morphology synthesized in a biphasic ionic liquid/water system. Pringle, J.M., Ngamna, O., Lynam, C., Wallace, G.G., Forsyth, M., MacFarlane, D. R. *Macromolecules,* 2007, 40, 2702-2711.
- High current density and drift velocity in templated conducting polymers. Winther-Jensen, B., Forsyth, M., West, K., Andreasen, J.W., Wallace, G., MacFarlane, D.R. *Organic Electronics,* 2007, 8, 796-800.

MILESTONE 43

Develop an all-polymer capacitor with capacity of the order of 100 F g^{-1} (End Year 3).

Carbon nanotube-polyaniline composite materials have been developed which produce very high capacitance values (~200 F/g after 1000 cycles). Work is continuing which will combine these electrode materials with a polymer electrolyte.

In other preliminary work carried out in collaboration with Prof. Ko (at Hanbat University, Korea) a capacitor consisting of polyaniline nanofibre electrodes with a PVDF (containing organic electrolyte) separator exhibited capacitance values around 100 Fg^{-1}. Issues with stability remain.

MILESTONE OUTPUTS

- Electrochemical performance of polyaniline nanofibers and polyaniline/ multi-walled carbon nanotube composite as electrode materials in redox supercapacitors. Sivakkumar S.R., Kim W.J., Choi, J., MacFarlane, D.R., Forsyth, M., Kim, D.W. *J Power Sources* 2007, 171, 1062-1068.
- Performance evaluation of CNT/ polypyrrole/MnO_2 composite electrodes for electrochemical capacitors. Sivakkumar, S.R., Ko, J.M., Kim, D.Y., Kim, B.C., Wallace, G.G. *Electrochimica Acta,* 2007, 52, 7377-7385.

MILESTONE 44

Develop fabrication techniques for flexible membrane structures utilising these materials (End Year 3).

Preliminary studies have commenced.

MILESTONE 45

Develop wet-spinning techniques that enable the use of wet-spinning to produce fibre batteries and supercapacitors (End Year 5).

The techniques to produce appropriate films have now been well established. However, the materials that could be spinable and give high capacity as well as stability still need to be identified.

MILESTONE 46

Integrate fibre batteries into textile structures (End Year 5).

Given the challenges in materials stability, this will not be attempted until suitable materials have been identified.

P4: BIONICS

P4-1 NERVE CELL COMMUNICATIONS

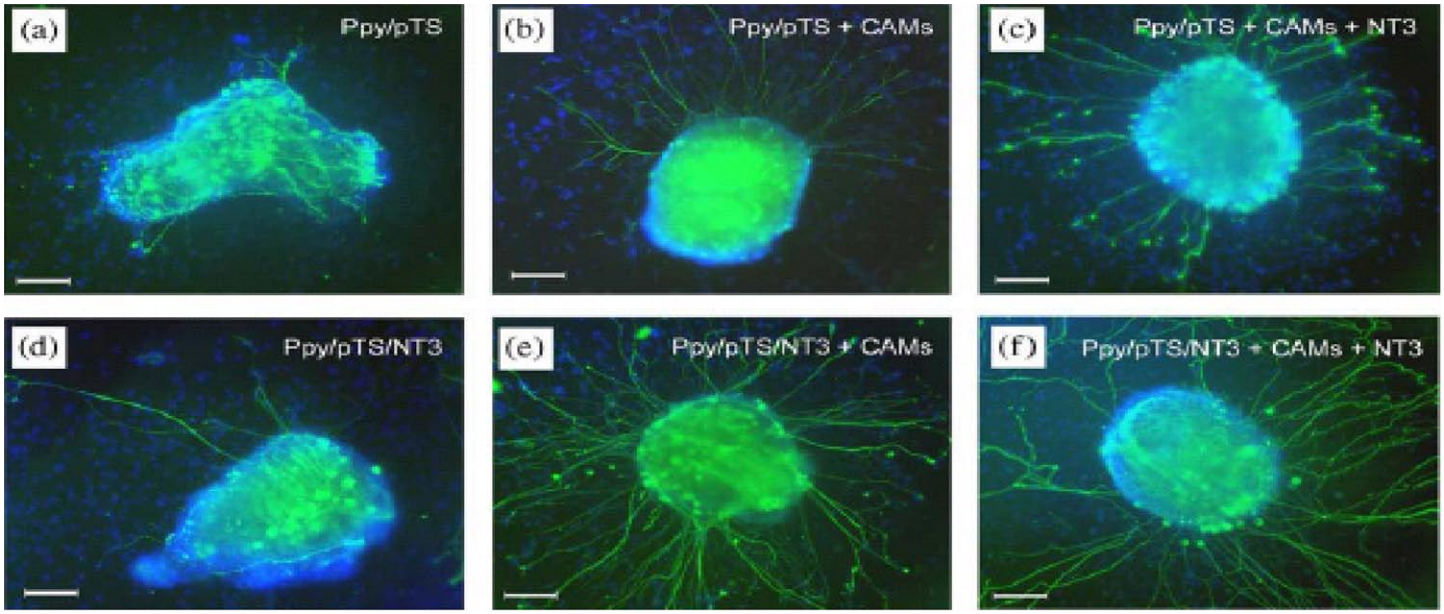
P4-2 BIO-STABILITY AND BIOCOMPATIBILITY

MILESTONE 47

An understanding of the interfacial chemistries required for efficient cell adhesion and cell proliferation (End Year 1).

Milestone 47, aimed at accruing fundamental knowledge on conducting polymer/cellular interactions, has been addressed by data gained on the effect of interfacial (dopant) chemistries on behaviour of primary neuronal structures (Dorsal Root Ganglia) and how this may be utilized in a neuroregenerative device.

Figure 9. Neurite outgrowth is affected by surface chemistry. SGN explants were grown on PPy/pTS or PPy/pTS/NT3, with or without a coating of CAMs and in media containing 0 or 40 ng/ml NT3. (a) Explants grown on uncoated PPy/pTS exhibited poor neurite outgrowth. (b) The addition of a CAM coating to PPy/pTS enhanced neurite outgrowth, as did (c) the inclusion of NT3 in the culture media. Compared to PPy/pTS, neurite outgrowth was also improved by incorporating NT3 into the PPy, exemplified by (d) this explant, grown on PPy/pTS/NT3. The addition of a CAM coating to PPy/pTS/NT3 (e) and NT3 to the media (f) made further dramatic differences to neurite outgrowth. Scale bars are 100 mm (Richardson et al., 2007).



Conducting polymers have been determined to have varied pro-neural biomimetic properties mediated by variations in dopant/surface chemistries and interactions with cell adhesion molecules. Work in this milestone has continued from these findings so as to gain a greater understanding of how the interfacial chemistries, most particularly the redox properties and surface nanostructural effects imparted by dopants used in ICP synthesis, induce biomimetic responses in cells **(Figure 9)**.

MILESTONE OUTPUTS

- Optimising the incorporation and release of a neurotrophic factor using conducting polypyrrole. Thompson, B.C., Moulton, S.E., Ding, J., Richardson, R., Cameron, A., O'Leary, S., Clark, G.M., Wallace, G.G. *Journal of Controlled Release,* 2007, 116, 285-294.
- The effect of polypyrrole with incorporated neurotrophin-3 on the promotion of neurite outgrowth from auditory neurons. Richardson, R.T., Thompson, B., Moulton, S., Newbold, C., Lum, M.G., Cameron, A., Kapsa, R., Clark, G., O'Leary, S., Wallace, G.G. *Biomaterials,* 2007, 28, 513-523.
- Conducting Polymers – Bridging the Bionic Interface. Wallace, G.G., Spinks, G. *Soft Matter*, 2007, 3, 665-671.

MILESTONE 48

An understanding of how energy transfer processes (electrical stimulation) influence these interfacial chemistries (End Year 2).

Work on Milestone 48 has focussed on the development and use of electrical stimulation to effectively release neurotrophins (NT3 and BDNF) from polypyrrole and to stimulate neuronal outgrowth from primary spiral ganglia structures (Spiral Ganglia) *in vitro*. The effect of electrically stimulated neurotrophin release was seen to augment the stimulation of neurite outgrowth compared to electrical stimulation alone.

These findings have been extended towards gaining a more detailed understanding as to how ICPs may be tailored for better control of specific biofactors' incorporation and release by electrical stimulation and towards elucidation of how electrical stimulation affects the molecular changes of proteinaceous species in contact with the ICPs. These extended studies, incorporating molecular modelling methodologies, have already indicated a possible (hydrophobic interaction) mechanism for neurotrophin (NT3) attachment to and release from polypyrrole. Further work will be carried out in this milestone in order to achieve this.

MILESTONE OUTPUTS

- Optimizing the incorporation and release of a neurotrophic factor using conducting polypyrrole. Thompson, B.C., Moulton, S.E., Ding, J., Richardson, R., Cameron, A., O'Leary, S., Wallace, G.G. and Clark, G.M. *J Cont. Rel.,* 2007, 116, 285–294.
- The effect of polypyrrole with incorporated neurotrophin-3 on the promotion of neurite outgrowth from auditory neurons. Richardson, R.T., Thompson, B., Moulton S., Newbold C., Lum, A.G., Cameron, A., Wallace, G.G., Kapsa, R., Clark, G., O'Leary, S. *Biomaterials,* 2007, 28, 513–523.

MILESTONE 49

Utilise and refine fibre fabrication protocols (P1) that allow for production of micro-devices to control the direction of neurite outgrowth (End Year 3).

Wet spinning protocols that enable biodegradable/conducting polymer structures to be produced have been developed. Preliminary cell culturing experiments involving nerve cells have commenced.

MILESTONE 50

Develop nanofabrication protocols that allow construction of 3-dimensional networks and devices for integration with fibrous tissue as well as cell adhesion and proliferation (End Year 5).

Not yet commenced.

P5: ETHICS

P5-1 BIOSYSTEMS, ELECTROMATERIALS AND COMMODIFICATION OF HUMAN HEALTH

MILESTONE 51

An understanding of the social-legal and ethical context of developments in bionics (End Year 2).

Preliminary research was undertaken on the rapidly changing socio-legal context of developments in bionics in Australia (and in international developments, e.g. UNESCO).

A paper on the social and ethical implications of bionics, human enhancement and the regulation of nanotechnology has been prepared.

MILESTONE OUTPUTS

- Dodds. S. Nanotechnology: social and ethical issues. Invited panellist on Ethical and Social Issues of Nanotechnology, International Conference on Nanoscience and Nanotechnology, Brisbane Convention and Exhibition Centre, July 2006.
- Kyle. R. Nanotechnology: Changing Social Relations. presented at *The Governance of Science and Technology;* A Joint GovNet/CAPPE/ UNESCO Conference 9-10 August 2007, Australian National University.
- Kyle, R., Dodds. S. Processes for public deliberation on the ethics of enhancement technologies and bionics. Paper submitted to ICONN 2008.
- Kyle. R. Sounding out the self: Ethical implications of bionic devices. ACES Full Centre Workshop, Melbourne, St. Vincent's Institute for Medical Research; October 3-4 2007.

MILESTONE 52

An understanding of the impact of commodification on the development of bionics and the clinical applications of bionics (End Early Year 3).

Preliminary research on commodification of medical bionics, role of research funding structures in driving bionics and regulation of bionics was carried out.

P5-2 "BIONIC PEOPLE"

MILESTONE 53

An understanding of the significance of bionics for self-identity and uses of the self: ethics and the self (End Year 3).

Preliminary preparation of paper on the ethics of medical bionics to be presented at The Sir Mark Oliphant Conferences - International Frontiers of Science and Technology : "*Medical Bionics – a new paradigm for human health"* (invited paper).

MILESTONE 54

Develop an integrated position on the development of bionics, human health and ethical relations (End Year 5).

This is work in progress, and dependent on the completion of other milestones.

EDUCATION MILESTONES

MILESTONE 55

Establishment of ethics program and first cohort of staff and students trained (End Year 1).

The ethics program has been established and the first cohort of students has been trained through the conduction of two workshops held in 2006. The Ethics and Regulation Workshops were two half-day events (at Monash University and at the University of Wollongong), supported through ACES and ARCNN for early career researchers and HDR candidates working in nanotechnology. The Workshops provided participants with an introduction to some emerging ethical and regulatory issues in nanoscience and nanotechnology; an opportunity to develop skills in identifying and articulating responses to ethical and regulatory issues through case studies; and an opportunity to meet, debate and hear the views of some key Australian researchers and practitioners in the areas of nanoethics and nanoregulation.

The workshops on ethics and regulation in nanotechnology were held in August 2006 at two venues, Wollongong and Monash. The events were hosted by ACES and partly sponsored by the ARC Nanotechnology Network. These two workshops were well-attended (approximately 35 participants at Wollongong and 18 at Monash) and well-received. Susan Dodds developed the case studies and facilitated the workshops. There were four invited speakers and support from Will Price (Wollongong) and Maria Forsyth (Monash) as well as other ACES staff. Each invited speaker presented their overview of the key issues for regulators and ethicists as these technologies emerge. At Wollongong the presenters were Prof John Weckert (Information Technology, Charles Sturt University and ARC Key Centre for Applied Philosophy and Public Ethics); Ms Diana Bowman (Law, Monash University) and Dr Peter Binks (NanoVic). At Monash Dr Rob Sparrow (Philosophy and Bioethics, Monash University) replaced Prof Weckert; Diana Bowman and Peter Binks presented at both workshops. Participants were encouraged to read the 2006 UNESCO Publication 'The Ethics and Politics of Nanotechnology' prior to the workshops.

At both workshops, participants were given the opportunity to work through some of the ethical and regulatory issues of nanotechnology through two cases. In the first, participants were asked to develop criteria for research assessors who were to set priorities in research funding based on the "national benefit" of nanotechnology research. This required participants to identify the different kinds of "goods" that nanoscience/ nanotechnology could generate, their relative importance for a society like Australia, the relative likelihood of different benefits being achieved in the foreseeable future and the significance of allocating public funding to different research areas. The second case asked participants in that group to identify what they considered to be the key factors of nanotechnologies that required some form of regulatory response; to explain why those factors were significant; and to explain what kind of regulatory structure would be appropriate for those concerns. All presenters offered commentary on the group discussion findings. It is anticipated that the workshops will be run again next year with the prospect of attracting good numbers of external delegates.

MILESTONE 56

Development of characterisation short courses and workshops (End Year 1).

The first in a series of characterisation workshops was held in Wollongong during 2006. The theme for the two day workshop was carbon nanotubes (CNTs) and the audience were internal members of ACES. The workshop featured both tutorial and hands-on sessions where delegates could see state-of-the-art facilities for synthesis and characterisation of CNTs. The feedback and lessons learnt form this workshop were used to mount a revised format for the program which was offered to external delegates in 2007. The format will also be used as a template for future events on characterisation techniques.

Workshops on characterisation and ethics have continued throughout 2007. See section on Education and Training.

MILESTONE 57

Full Development of community outreach programs at Monash and Wollongong Science Centres (End Year 3).

Discussions are underway concerning exhibits and ongoing interactions.

Appendix II

ARC CENTRE STUDENTS

Name	Host Institution	Commenced	Title	Financial Arrangements
Nickita Rajoo	Monash	2003	Development of Biosensors Based on Peptide Nucleic Acids.	ARC
Gary Annat	Monash	2004	Ionic Liquids for stable lithium cathode materials.	CSIRO Li Project funds
Mehrdad Samani	IPRI/UoW	2004	Modelling of polypyrrole helix tube actuators	Iranian Government
Liu Yong	IPRI/UoW	2004	Nanostructured electrodes based on carbon nanotubes.	UoW. ARC scholarship
Orawan Ngamna	IPRI/UoW	2004	Synthesis and characterisation of ICPs nanoparticles.	UoW. ARC scholarship
Jenny Causley	IPRI/UoW	2004	Use of electrode nanostructures for fluid movement.	UoW scholarship/ARC top up
See How Ng	ISEM/UoW	2004	Nano-structured materials for electrode in Li-ion battery.	UoW
Tracey Markly	Monash	2005	Electrochemical and Surface characterisation of rare earth inhibited aluminium alloys	Monash
Youssof Shekibi	Monash	2005	Novel Plastic Crystal Electrolyte Materials	ARC & CSIRO Energy Technology top up.
Xiao Liu	IPRI/UoW	2005	Cell culturing on organic conductors	ARC Centre scholarship
Salvador Larios	IPRI/UoW	2005	Hydrogel micro and nano actuators	IPRS
Stephen John	UoW	2005	Conducting polymer based micro and nano manipulation systems	APA
Brianna Thompson	IPRI/UoW	2005	Cell culturing on conducting polymers	APA scholarship/ARC top up
Min Sik Park	ISEM/UoW	2005	Thin film lithium-ion batteries	ISEM
Stephen Zhang	Monash (undergrad)	2005	Mg alloy corrosion protection using IL treatments	ARC
Katarina Johansson	Monash	2005	New ionic liquids	Monash
Sau Yen Chew	ISEM/UoW	2006	Develop highly conductive nanocomposite electrolytes and electrodes for lithium batteries	ARC
Javad Foroughi	IPRI/UoW	2006	Nanostructured fibres	ARC
Andrew Nattestad	Monash	2006	Dye Sensitised Tandem Solar Cells for Improved Conversion Efficiency	Monash
Wayne Neil	Monash	2006	Effect of composition and morphology on reactivity of magnesium alloys & constituent metals	Monash
Aleksey Izgorodin	Monash	2006	Synthesis and characterisation of electroluminescent inorganic nanoparticles	ARC
Wen Zheng	IPRI/UoW	2007	Polypyrrole actuators	Federation Fellow UoW Scholarship
Sina Nafici	IPRI/UoW	2007	Novel biopolymer fibres	Federation Fellow UoW Scholarship
George Lee	IPRI/UoW	2007	Controlled Release of Nano Particles from Conducting Polymers	UoW
Dillip Panda	IPRI/UoW	2007	Development of Photoactive Polymer	UoW/ARC
Benjamin Mueller	IPRI/UoW	2007	Aligned Carbon Nano Tube-Biopolymer Structures	Federation Fellow UoW Scholarship
Robert Breukers	IPRI/UoW	2007	Biodegradable Conducting Polymers	APA/ARC top up
Shannon Little	IPRI/UoW	2007	Nanostructured Organic Conducting Electrodes	APA/ARC top up
Suriya Ounnunkad	IPRI/UoW	2007	Carbon Nanotube Biosensors	UoW
Charles Mire	IPRI/UoW	2007	Ink-Jet printing of Composite Materials	Federation Fellow UoW Scholarship
Grace Stevenson	IPRI/UoW	2007	In-Situ Raman-Electrochemical Studies in Ionic Liquids	Federation Fellow UoW Scholarship
Alberto Rodriguez	IPRI/UoW	2007	Nanobionic Materials	Federation Fellow UoW Scholarship
Rajeswari Thayumanavan	UoW	2007	Fullerenyl Amino Acids as Nanostructures	UoW/ARC
Shulei Chou	ISEM/UoW	2007	Nano-structured anodes in Li-ion rechargeable batteries	UoW

Appendix III

INVITATIONS TO ADDRESS INTERNATIONAL CONFERENCES

ACES staff presented a number of invited conference presentations at international events:

Date	Speaker	Affiliation	Type of presentation	Title of presentation	Name of conference/-meeting
Feb	Prof Gordon Wallace	IPRI, UoW	Invited	Carbon Nanotubes – New Bionic Materials	AMN-3 Third International Conference on Advanced Materials and Nanotechnology, Wellington, New Zealand,
Feb	Prof Doug MacFarlane	Monash	Invited	Electropolymerisation of Conducting Polymers in Ionic Liquids	3rd Int Conference on Electroactive Polymers, Goa, India
Feb	Prof Graeme Clark	BEI/SVHM	Plenary	The Bionic Ear: Passion in Science	Cochlear Celebration, San Antonio, USA
Feb	Shannon Little	IPRI, UoW	Invited	"Preparation, Characterisation and Applications of Novel Redox-Functionalised Conducting Polymers"	29th Australasian Polymer Symposium
Feb	Prof Maria Forsyth	Monash	Invited	Super-mobile charge carriers in Templated Conducting Polymers	3rd Int Conference on Electroactive Polymers, Goa
Feb	Prof Doug MacFarlane	Monash	Invited	Electropolymerisation of Conducting Polymers in Ionic Liquids	3rd Int Conference on Electroactive Polymers, Goa
Mar	Prof Graeme Clark	BEI/ SVHM	Guest of Honour Presentation	Cochlear implant story and Spoken Language	Hear & Say (Alexander G Bell Assoc) Australian conference on Listening and Spoken Language, Queensland, Aust
Mar	A/Prof Gursel Alici	UOW	Invited	Tri-layer polymer actuators with variable dimensions	SPIE 14th International Symposium on Smart Structures and Materials, and Nondestructive Evaluation and Health Monitoring
Apr	Prof David	IPRI, UoW	Invited	Shedding Light on a Sustainable Energy Future – is Artificial Photosynthesis the Key?	Launch of the University of Wollongong Energy Futures Network, University of Wollongong, Wollongong.
May	Prof Gordon Wallace	IPRI, UoW	Invited	Nanobionics: What role can organic conductors play?	Annual General Meeting 2007, Science at the Shine Dome, Canberra
May	Prof David Officer	IPRI, UoW	Invited	Solar energy the key to a sustainable future?	Illawarra Innovation Showcase Forum, Science Centre and Planetarium, Wollongong.
May	Prof Leon Kane-Maguire	IPRI, UoW	Keynote	Organic Conducting Fibres: Wearable to Medical Implants	6th National Iranian Textile & Engineering Conference, Ispohan University of Technology, Isfohan, Iran
May	Prof David Officer	IPRI, UoW	Invited	Energy transfer and Nanostructures:_ From Solar Cells to Bionics.	International Symposium on University-Industry Collaboration – In Commemoration of the 80th Founding Anniversary of Hanbat University, Hanbat University, Daejon, Korea.
May	A/Prof Paul Keller	UoW	Invited	Strategies Towards Fullerenyl Amino Acid Derivatives	211th Electrochemical Society Meeting
May	Prof Maria Forsyth	Monash	Plenary	Taming the Reactive Metal; Passive Surface Film formation in Ionic Liquids	ICAMN07 Langkawi Malaysia
May	Prof Maria Forsyth	Monash	Invited	Ionic Liquids	Science at the Shine Dome, Canberra
Jun	Prof Rob Kapsa	BEI/ SVHM	Lecture	Autologous cell transplant for neuromuscular disease	CPMC Lectures
Jul	Prof. Hua Liu	ISEM, UoW	Plenary & Chairman for invited session 6	Nanomaterials for use in lithium rechargeable batteries	2007 CAS International symposium on nanomaterials, nanodevices and thin film solar cells
Jul	Prof Doug MacFarlane	Monash	Keynote	Plastic Crystal Ion Conductors	Solid State Ionics 16, Shanghai
Jul	Prof Maria Forsyth	Monash	Invited	Nanocomposite Plastic Crystal Electrolytes	Solid State Ionics 16, Shanghai
Jul	Dr Bjorn Winther-Jensen	Monash	Invited	Structure and transport in templated conducting polymers	International Conference for Materials for Advanced Technologies, Singapore
Jul	Prof Maria Forsyth	Monash	Plenary	Ionic Liquids	30th Int Conf on Solution Chemistry, Perth

Date	Speaker	Affiliation	Type of presentation	Title of presentation	Name of conference/-meeting
Jul	Prof David Officer	IPRI, UoW	Plenary	Artificial Photosynthesis: Designing New Materials for Light Harvesting	14th International Congress on Photosynthesis: Solar Energy and Artificial Photosynthesis Satellite Meeting, The Royal Society, London.
Jul	Prof David Officer	IPRI, UoW	Invited	Organic Photovoltaics: Designing Aromatic Molecules to Save the Planet!	12th International Symposium on Novel Aromatic Compounds, Awaji Island, Japan.
Aug	Prof Gordon Wallace	IPRI, UoW	Invited	Nanostructured Organic Conductors – Bridging the Bionic Interface	SBE's 3rd International Conference on Bioengineering and Nanotechnology (ICBN2007), Biopolis, Singapore.
Aug	Prof Graeme Clark	BEI/ SVHM	Invited		Hearing Awareness Week Launch (Award Recipient – Peter Howson Medal), The Jasper Hotel Melbourne
Aug	Prof Doug Macfarlane	Monash	Plenary	Pharmaceutical Ionic Liquids	2nd Congress on Ionic Liquids, Yokohama, Japan
Aug	Prof Maria Forsyth	Monash	Plenary	Novel Ionic Liquid surface treatment for the protection of Mg alloys	2nd Congress on Ionic Liquids, Yokohama, Japan
Aug	Dr Renee Kyle	IPRI, UoW	Invited	Nanotechnology: Changing Social Relations	The Governance of Science and Technology; A Joint GovNet/CAPPE/UNESCO Conference, ANU
Aug	Prof Graeme Clark	BEI/ SVHM	Invited		Zulch-Prize, Cologne, Germany (Award Recipient – Zulch Prize), Gertrud Reemtsma Foundation, Max-Planck Institute for Brain Research
Sep	Prof Graeme Clark	BEI/ SVHM	Guest award presenter		2007 Prime Minister's Prizes for Science Awards, Canberra
Oct	A/Prof Paul Keller	UoW	Invited	The Study of Fullerenyl Amino Acids for Nanotechnology and Medicinal Chemistry	CSIRO
Oct	Dr. Zaiping Guo	ISEM, UoW	Invited & Chairman of session F	The impact of nanocomposites on lithium ion batteries	2007 NMS III International Nanomaterials symposium
Oct	Shannon Little	IPRI, UoW	Invited	"Multifunctional Conducting Polymers using a Conductive Electroactive Dopant"	Dublin City University symposium "Polymers Down Under Make Irish Sense"
Oct	Prof Graeme Clark	BEI/ SVHM	Guest of honour	The Cochlear Implant: From Bench to Bedside	Australian Orthopaedic Association Conference, Gold Coast Convention Centre
Nov	Prof Graeme Clark	BEI/ SVHM	Plenary	Future dreams for cochlear implants and other technologies to relieve deafness	APSCI Conference 2007 6th Asia Pacific Symposium, Sydney Convention Centre
Nov	Simon Moulton and Gordon Wallace	IPRI, UoW	Invited	Controlling the Electrode – Cellular Interface using Organic Conductors	MRS Fall Meeting, Boston, USA
Nov	Prof Maria Forsyth	Monash	Invited	Passivation of Reactive Metals using Novel Chemical Treatments	Corrosion Prevention 2007, Sydney
Nov	A/Prof Gursel Alici	UoW	Invited	How functional are conducting polymer actuators? Some application attempts	4th World Congress on Biomimetics, Artificial Muscles and Nano-Bio
Dec	Prof Graeme Clark	BEI/ SVHM	Invited		Lifetime Achievement Award Dean, Faculty of Medicine, Nursing and Health Science Monash University (Award Recipient – Lifetime Achievement Award)
Dec	Prof Gordon Wallace	IPRI, UoW	Plenary	Conducting Organic Nanostructures and their use in Medical Bionics	SPIE Microelectronics, MEMS, and Nanotechnology, The Australian National University, Canberra, Australia.
Dec	A/Prof Chee Too, Prof David Officer and Prof Gordon Wallace	IPRI, UoW	Plenary	Light Harvesting Materials and Nanostructured Electrodes for Organic Solar Cells	International Conference on Microwaves and Optoelectronics (ICMO 2007), The University of Aurangabad, India
Dec	Prof Leon Kane-Maguire	IPRI, UoW	Invited	Electromaterials for Bionics Applications: Controlling the Electrode – Cellular Interface using Organic Conductors	Indo-Australian Symposium on Multifunctional Nano Materials, Nanostructures and Applications (MNNA 2007), The University of Delhi, India.

Appendix IV

ACES VISITORS 2007

ACES hosted a large number of visitors from research organisations and industry from within Australia and overseas:-

- Dr Phillip Aitchison - Cap-XX
- Dr. Penny Marten - University of NSW
- James Nicholson - Schefenacker
- Dr Ray Shaw - Rio Tinto
- Dr Evan Evans - BlueScope Steel
- Dr Christina Baker - UCLA
- Dr Dave Martin - University of Michigan, USA
- Dr Tan Truong - DSTO
- Prof Frank Walsh - University of Southampton, UK
- Prof Dennis Tallman - NDSU, USA
- Dr Ian McKinnon - Australian Research Council
- Prof Tom Miyasaka - Peccell Technologies (Japan)
- Prof David Carroll - Wake Forest University, USA
- Prof Laura Poole-Warren - UNSW
- Dr John Carras - CSIRO
- Dr Ian Dagley - CEO, CRC Polymers
- Prof Sung-un Cho - Sunchon University (Korea)
- Dr David Rand - CSIRO
- Prof Zi Feng Ma - JiaTong University, Shanghai (China)
- Prof Ray Baughman - University of Texas, Dallas, USA
- Dr Peter Verdru - UCB
- Prof. Chennupati Jagadish - Australian National University
- Dr Suzi Jarvis - Trinity College Dublin, Ireland
- Dr Jan Weber - Boston Scientific, USA
- Dr Raviprasad Krishnamurthy - Nanovic
- Dr Liang Qiao - The University of Hong Kong
- Dr Alan Jones - Australian National University
- Dr Alessandro Zedda - Ciba Basel, Switzerland
- Dr Ryuichi Takahashi - Ciba Amagasaki, Japan
- Dr Karl Crowley - DCU, Ireland
- Dr Roger Knight - Aqua Diagnostics
- Dr John Dell - University of Western Australia
- Dr Chang Kee Lee - Hanyang University, Korea
- Dr Min Sup Kim - Hanyang University, Korea
- Dr Pall Thordarson - University of Sydney
- Dr Jim Patrick - Cochlear
- Dr Martin Svehla - Cochlear
- Dr James Nicholson - Schefenacker
- Dr Kurt Wilfinger - Schefenacker
- Prof. Robert Short - University of South Australia
- Dr Ingrid Arnott - ABC
- Dr Gerry Swiegers - CSIRO
- Dr Levin Kuhlmann - Bionic Implants, Melbourne
- Dr Rosie Hicks - ANFF
- Dr Ross Lewin - University of Connecticut, USA
- Dr John Carras - CSIRO
- Dr Cameron Briggs - CSIRO
- Dr Khai Leok Chan – Singapore
- Dr Colin Lamond - CEO of Metal Manufactures
- Prof Dongwon Kim - Hanbat University, Korea
- Prof Austen Angell - Arizona State University
- Robert Byrne - Dublin City University, Ireland
- Prof John Owen - University of Southampton, UK
- Prof Rudi Bucheit - Fontana Corrosion Institute, OSU, Ohio, USA
- Prof John Scully - Director Centre for Electrochemical Science and Engineering, University of Virginia
- Dr Eun-Hee Cha - Korean National University
- Prof. Lillia Kuleshova - National University of Singapore
- Dr. G. Ramanath - Rensselaer Polytechnic Institute, USA
- A delegation (Assoc Prof Xingwu Guo and Assoc Prof Shifeng Wang) - Shanghai Jiao Tong University, China
- A delegation (Prof Ying Liu , Assoc Prof Jianxun Cheng , Prof Qingyuan Wang , Prof Guochun Hua, Prof Jianwu Lan, Prof Shiping Zhao) - Sichuan University, China

Appendix V

MEDIA COVERAGE

Date	Medium	Source	Description	Impact	Journalist
January	TV	Channel 10 Today Show	Interview re Neural Repair	Positive	David Reyne & Kim Watkins
January 31	Print	Daily Telegraph	The Australian scientist who pioneered the bionic ear is working to help paraplegics walk again. Mentions UOW.	Positive	Kate Jones
January 31	Print	Herald Sun	Researchers at UOW, St Vincent's Hospital and the Bionic Ear Institute are working on the bionic ear implant.	Positive	Kate Jones
January 31	Radio	3AW Melbourne	Fed Govt, UOW and Uni of Melbourne and the Australian Research Council of Excellence have contributed funds needed for research into the bionic ear.	Positive	
January 31	Radio	3AW Melbourne	UOW and University of Melbourne are working together to research the bionic ear.	Positive	Grant Goldman
January 31	Web	www.news.com.au	The Melbourne scientist who pioneered the bionic ear is working to help paraplegics walk again. Mentions UOW.	Positive	Kate Jones
February 7	Print	Herald Sun	Front page Article on new research 14 radio and 2 TV interviews	Positive	Cheryl Critchley
February 8	Television	WIN TV	UOW and University of Melbourne are working together to research the bionic ear.	Positive	Geoff Phillips
February	Print	Herald Sun	"Greatest" series – Learn section	Positive	Nick Higginbottom
February	Radio	ABC Newcastle	Interview re Neural repair	Positive	Nickki Bollinger
February	Print	Scripps Howard News Service, USA	Interview re cochlear implants	Positive	Michaela Jackson
February 17	TV	Fox 29 San Antonio, USA	Re Implantable hearing device	Positive	San Antonio Express – News and Scripps Howard
February 17	Online video broadcast	KENS 5, San Antonio, USA	Re Implantable hearing device	Positive	Local news medical story
February 17	TV	NBC San Antonio, USA	Re Cochlear implants	Positive	News coverage
March 8	Radio	ABC 612 Brisbane	Interview (Hear & Say Conference)	Positive	Madonna King
March 15	Print	Readers Digest	Interview	Positive	Helen Signy
March	Print	The Bulletin	Smart 100 list Entry	Positive	Katherine Fleming
March	Print	The Age Newspaper	Melbourne Quiz	Positive`	Peter Barrett
March 24	Print	Illawarra Mercry	Nanotechnology is being used at UOW to create cheap, light organic solar cells by a team led by Prof Gordon Wallace.	Positive	Veronica Apap
March 24	Print	Illawarra Mercury	UoW academic Prof Susan Dodds who works on the ethics of nanotechnology comments on NSW Greens' call for a moratorium on the commercial sale of nanotechnology products (Article headline "Nanotechnology no-no, warns Greens")	Positive	Veronica Apap
March 27	Radio	ABC Illawarra	A researcher in nanotechnology at UOW Prof Gordon Wallace says caution is taken when dealing with atomic material at the research level.	Positive	
April 3	Magazine	Campus Review	Sixteen of Australia's leading scientists were honoured last week by election to the Australian Academy of Science. Includes Prof Gordon Wallace, UOW.	Positive	
April 5	TV	Catalyst Program, ABC TV	Interview 22 years of the Bionic Ear	Positive	Simon Watt
April	Book	"Ten Greatest medical Breakthroughs"	What the Experts Say section	Positive	Denis Carr, guest Author Rubicon Publishing
April 11	Print	Honda Magazine	Interview	Positive	Stuart Sykes

Date	Medium	Source	Description	Impact	Journalist
April 22	Radio	Mal Garvin's Radio Program	20 minute interview	Positive	Mal Garvin
May 1	Print	Australian R&D Review	The Australian Academy of Science has elected sixteen new Fellows, including UOW's Prof Gordon Wallace.	Positive	
May 8	Print	The Illawarra Mercury	UoW solar expert Professor David Officer was interviewed about the Public Forum on Energy Options for 2020 being held tonight in which he is a panel member.	Positive	
May 11	Newswire	The Australian Associated Press	The Australian Associated Press (AAP) newswire carried a story about how researchers have teamed up to tap the sun's energy with plastics. It said the appearance of incentives for solar energy in the Federal Budget is a sign that politicians are sitting up and taking notice of this alternative, clean energy source. AAP noted that the scientific community is also taking solar very seriously as earlier this year an international task force of 13 research teams held its inaugural meeting at UOW. David Officer (IPRI) quoted.	Positive	
May 21	Print and electronic	Media Release through UoM National and international coverage	Inventor of Cochlear implant wins top German neuroscience award	Positive	Rebecca Scott, Media Officer, UoM
May 21	Print and electronic	Media Release through UoM	Electrical Pulses Research	Positive	Rebecca Scott, Media Officer, UoM
May 24	Print	Canberra Times	Nano bionics gives hope to paraplegics, according to Prof Gordon Wallace, UOW.	Positive	Danielle Cronin
May 30	Print	Diamond Valley Leader	Honour for Professor. Editorial in recognition of the Zulch Prize from the Max Planck Society	Positive	Fiona Willan
June 3	Print	Bayside Leader	Announcement of Professor MacFarlane's Federation Fellowship	humorous	
June 11	Website	BBC	Dr Yanhze Wu from Dublin City University cycles up a storm in this article featured on the BBC website, "Smart Clothes to Monitor Health."	Positive	
June 17	Radio	Sydney 2CH "Connections"	Bringing hearing to the deaf, faith and experimentation and development of the bionic ear	Positive	Roslyn Simms, Producer Macquarie Radio
August 21	Radio	ABC Illawarra	A radio interview on ABC Illawarra radio (7.40am) with Professor Gordon Wallace.	Positive	Peter Riley
August 22-23	Print	The Illawarra Mercury	The Illawarra Mercury reported that a new bionics team set to rival any other in the world has now been assembled at the University of Wollongong and is already preparing to host the first Asia Pacific Symposium on Nanobionics in June 2008. Professor Gordon Wallace (IPRI/ACES) is quoted.	Positive	
September 11	Print	The Illawarra Mercury	The Illawarra Mercury interviewed Gordon Wallace about his dream of developing artificial limbs and how it could be realised in as little as five years with the start of a new bionics program at UOW. The story also focused on PhD student Javad Foroughi who was helping to create the "bionic dream" through fibre production.	Positive	
October	Print	Campus News, University of Wollongong	Story on UoW solar expert Professor David Officer as one of the speakers at the 14th International Congress on Photosynthesis: Solar Energy and Artificial Photosynthesis Satellite Meeting, The Royal Society, London.	Positive	
October	Magazine	Honda, The Magazine	"Striking the Right Cord" in Honda, THE MAGAZINE Issue 41, Spring 2007. This article is an interview with Professor Graeme Clark about his taking on the challenge to "stem the tide of consequences flowing from spinal cord injury".	Positive	
October 24	TV	ABC	ABC TV's Catalyst program featured Gordon Wallace who discussed how electrotextiles can contain sensors to allow people to do a range of things such as exercise properly, improve golf swings and even change the colour of their clothing.	Positive	
October 25	Print	Illawarra Mercury	UOW academic Dr Andrew Minett who works in the Intelligent Polymer Research Institute writes of his work on a collaborative team developing bionic technology.	Positive	
December 18	TV	Channel 9	Dr Toni Campbell and Professor Julie Steele (UoW) were on Channel 9 TV "A Current Affair" demonstrating how conducting fabric sensors on brassieres are used to measure vertical breast motion.	Positive	

Appendix VI

STAFF MEMBERS OF THE CENTRE

Member	Role	Affiliation
Prof. G.G. Wallace	Executive Director and Program 1 Co-Leader	University of Wollongong
Prof. M. Forsyth	Associate Director	Monash University
Prof. D.L. Officer	Program 1 Co-Leader	University of Wollongong
Prof. G.M. Spinks	Program 2 Leader	University of Wollongong
Prof. D.R. MacFarlane	Program 3 Leader	Monash University
Prof. G.M. Clark	Program 4 Co-Leader	Bionic Ear Institute
A/Prof. R. Kapsa	Program 4 Co-Leader	University of Wollongong
Prof S. Dodds	Program 5 Leader	University of Wollongong
Prof. W.E. Price	Education Director	University of Wollongong
A/Prof C.O. Too	Chief Operating Officer	University of Wollongong
Prof. L.A.P. Kane-Maguire	Chief Investigator	University of Wollongong
Prof. H.K. Liu	Chief Investigator	University of Wollongong
A/Prof. P. Keller	Chief Investigator	University of Wollongong
Prof. H. Brown	Chief Investigator	University of Wollongong
A/Prof. P. Innis (QEII)	Chief Investigator	University of Wollongong
Dr. A. Minett (QEII)	Chief Investigator	University of Wollongong
A/Prof. G. Alici	Chief Investigator	University of Wollongong
Prof. L. Spiccia	Chief Investigator	Monash University
Prof. Y-B. Cheng	Chief Investigator	Monash University
Dr A. Mozer	Research Fellow	University of Wollongong
Dr D. Sharma	Research Fellow	University of Wollongong
Dr J. Razal	Research Fellow	University of Wollongong
Dr P. Wagner	Research Fellow	University of Wollongong
Dr R. Shepherd	Research Fellow	University of Wollongong
Dr S. Moulton	Research Fellow	University of Wollongong
Dr. D. Li	QEII Fellow	University of Wollongong
Dr J. Wang	Research Fellow	University of Wollongong
Dr C. Wang	Research Fellow	University of Wollongong
Dr R. Kyle	Research Fellow	University of Wollongong
Dr. S. McGovern	Research Fellow	University of Wollongong
Dr D. Nayagam	Research Fellow	Bionic Ear Institute
Ms K. Shipham	Research Assistant	Bionic Ear Institute
Dr J. Pringle	QEII Fellow	Monash University
Dr J. Sun	Research Fellow	Monash University
Dr P. Newman	Research Fellow	Monash University
Dr G. Gasser	Research Fellow	Monash University
Dr P. Howlett	Research Fellow	Monash University
Dr U. Bach	ARC Fellow	Monash University
Dr S. Pas	ARC Fellow	Monash University
Dr B. Winther-Jensen	APD Fellow	Monash University
Dr K. Izgorodina	Research Fellow	Monash University
Dr H. Han	Research Fellow	Monash University
Mr L. Edmond	Research Fellow	Monash University

Member	Role	Affiliation
Prof. S. Adeloju	Associate Investigator	Monash University
Prof J-H. Ahn	Associate Investigator	Andong National University
Prof A. Bond	Associate Investigator	Monash University
Prof. D.N. Butler	Associate Investigator	University of Wollongong
Dr D. Buxton	Associate Investigator	BlueScope Steel Limited
Dr E. Evans	Associate Investigator	BlueScope Steel Limited
Dr T. Bastow	Associate Investigator	CSIRO-Manufacturing Science & Technology
Dr T. Hollenkamp	Associate Investigator	CSIRO Energy Technology
Dr G.F. Swiegers	Associate Investigator	CSIRO-Molecular and Health Technologies
Dr W. Humphries	Associate Investigator	CSIRO-Textile & Fibre Technology
Dr A. Hill	Associate Investigator	CSIRO-Manufacturing Science & Technology
Prof. S. De Leeuw	Associate Investigator	Delft University of Technology
Prof. L. Dai	Associate Investigator	Wright Brothers Institute
A/Prof P. Dastoor	Associate Investigator	University of Newcastle
Prof. D. Diamond	Associate Investigator	Dublin City University
Prof. R. Forster	Associate Investigator	Dublin City University
Prof J. Hill	Associate Investigator	University of Wollongong
Prof. A. Ivaska	Associate Investigator	Abo Akademi University
A/Prof S.J. Kim	Associate Investigator	Hanyang University
Prof. J-Y. Lee	Associate Investigator	Korean Institute of Metals and Materials
Assist. Prof. J. Madden	Associate Investigator	University of British Columbia
Dr P. Poulin	Associate Investigator	CNRS
A/Prof S. Ralph	Associate Investigator	University of Wollongong
Prof. L. Samuelson	Associate Investigator	University of Massachusetts Lowell
Prof. M.E. Smith	Associate Investigator	University of Warwick
Prof. D.E. Tallman	Associate Investigator	North Dakota State University
Prof D. Theodorou	Associate Investigator	National Technical University of Athens
Dr V-T. Truong	Associate Investigator	DSTO
Prof F. Walsh	Associate Investigator	University of Southampton
Prof R.N. Warrener	Associate Investigator	University of Wollongong
Prof K. West	Associate Investigator	Riso National Laboratory
Dr Z. Guo	Associate Investigator	University of Wollongong
Dr K. Konstantinov	Associate Investigator	University of Wollongong
Dr G. Wang	Associate Investigator	University of Wollongong

Appendix VII

INTELLECTUAL PROPERTY REGISTER

FOR THE ARC CENTRE OF EXCELLENCE FOR ELECTROMATERIALS SCIENCE

			Intellectual Property (IP) Details		
Centre Program	**Organisation**	**Names of Inventors**	**Background IP**	**New IP**	**Date**
2	UoW/IPRI	G.M. Spinks, G.G. Wallace, D. Zhou	PCT/Au02/01608, "An electrochemical actuator and means of providing same".		Nov. 2001
3	UoW/ISEM	G.X. Wang, K. Konstantinov, H.K. Liu, S.X. Dou	Innovation Patent No: 2002100000 "Cathode materials for rechargeable batteries and a process for production"		Jan. 2002
3	UoW/ISEM	S.X. Dou, K. Konstantinov, H.K. Liu, G.X. Wang	Innovation Patent No: 2002100190, "Fabrication of cathode materials for li-ion batteries"		Mar. 2002
3	UoW/ISEM	K. Konstantinov, G.X. Wang H.K. Liu, S.X. Dou S. Bewlay	Innovation Patent No: 2002100403 "Development of new positive compounds for lithium-ion batteries"		May 2002
1	UoW/IPRI Trinity College Dublin	G.G. Wallace, S. Moulton, A. Minett, W. Blau	Provisional patent. PCT lodged, "Use of biomolecules as selective dispersants for carbon nanotubes".		Feb. 2003 Feb. 2004
3	Monash/CSIRO	P. Howlett, T. Hollenkamp, D. MacFarlane and M.Forsyth	PCT/AU2004/000263 Energy Storage Devices		Mar. 2004
1	UoW/IPRI/ Virginia Tech	M. Bennett, D. Leo, G. Spinks, G. Wallace	US Patent Ionic solvents for ionic polymer transducers		Aug 2004
1 and 3	Monash	P. Howlett, D. MacFarlane, M.Forsyth	Aust. Prov. Patent, 2005901074 "Ionic liquid surface treatments for reactive metals and their alloys"		Mar 2005
1	UoW/IPRI	Wallace, G.G., Innis, P.C., Mazurkiewicz, J., Edwards, S.	Provisional Patent Application No. 2005903481. "Charge Conducting Medium"		July 2005
1	Monash/CSIRO	N. Byrne, P. Howlett, T. Hollenkamp, D. MacFarlane and M.Forsyth	US Provisional Patent Application No. 60/603524 (20 Aug 2004) PCT AU2005 001237 "Zwitterionic Additives for Electrochemical Devices"		Aug 2005
1	Monash/CSIRO	D.R. MacFarlane, A.F. Hollenkamp, P.C. Howlett, M. Forsyth, C. Tiyapiboonchaiya, J.M. Pringle & N. Byrne,		PCT Int. Appl. 70 pp. "Zwitterionic Additives for Electrochemical Devices"	2006
1	UoW/IPRI	C. Lynam, P. Whitten, S. E. Moulton, G. G. Wallace		Provisional Patent "Biocompatible Composites"	3rd February 2006
2	UoW/IPRI	Diamond, D., Shepherd, R., Smyth, C., Wallace, G.G., Spinks, G.M., Wu, Y.		US Provisional Patent Application No.: 60/772,627. "A Self-Maintained Sensor using a Low Power Actuator"	13th February 2006

Centre Program	Organisation	Names of Inventors	Intellectual Property (IP) Details		Date
			Background IP	New IP	
1	IPRI/BEI	Chen, J., Minett, A., Wallace, G.G., Clark, G.M.		Aust. Prov. Patent 'Nanostructured composites', AU2006907002	30th June 2006
1	IPRI	Chen, J., Minett, A., Wallace, G.G.		Aust. Prov. Patent 'Nanocomposites', AU2006903544	14th December 2006
4	BEI/Monash	Graeme M. Clark, David B. Grayden,		Electrophonic Hearing Patent Application	2006
4	BEI/Monash	Graeme M Clark		An Implantable Device and an Implantation Process	2006
4	BEI/Monash	Graeme M Clark, David B Grayden		Nanostructured Conductive Biomaterials	2006
1 and 4	IPRI/BEI	Wallace, G.G., Chen, J., Minett, A.I., Clark, G.M.		Nano-structured Composites (Aligned CNT Electrode Structure). Prov 2006903544. PCT filed. No PCT number yet (GH ref P61180.PCT)	PCT filed 29 June 2007