Australian Government

Invest Australia

Nanotechnology

Australian Capability Report

Third Edition

Imagine a brighter future Australia

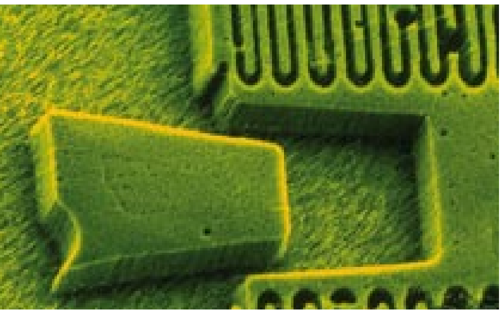
Published May 2007

ISBN 0 642 72457 1
Prod No. IA 046

Front cover image: Professor Michelle Y Simmons, Director of Atomic Fabrication Facility, Centre for Quantum Computer Technology at UNSW, working in the Lab.
This Page: A nanostar. Image courtesy of CSIRO

Contents

Overview



Nanotechnology developed at the CSIRO. Image courtesy of CSIRO.

Australia is making a name for itself in materials, nano-biotechnology, electronics and photonics, energy and environment and quantum technology. Research outcomes can be applied across a wide range of industries, from agriculture and IT to health and aeronautics.

Global companies in every major industry have benefited from Australian nanoscience, from aeronautics (The Boeing Company, Airbus Deutschland GmbH) and information technology (Intel, Sony) to health (Merck, Pasteur Institute of France) and resources (Rio Tinto). In addition to companies, foreign government agencies and international research institutes are investing in Australian nanotechnologies, with significant results in the manufacturing, raw materials and environmental sectors.

Its smart, enterprising population, robust R&D infrastructure, supportive government and stringent IP protection make Australia an attractive location to establish and conduct research activities.

The Australian Government's Backing Australia's Ability strategy is a multi-billion dollar initiative that ensures a steady stream of funding for scientific research and commercialisation. This funding is augmented by significant contributions from the state and territory governments and the private sector.

As part of its May 2007 Industry Statement, the Australian Government announced new funding for a National Nanotechnology Strategy and a Niche Manufacturing Flagship, which will focus on the development of nanotechnology applications.

The Australian Government has also announced changes to the 175% Research and Development Tax Concession, which will extend access to multinational enterprises which undertake Research and Development (R&D) in Australia but hold the intellectual property offshore.

Collaboration is a defining feature of the Australian nanotechnology sector. The country's research institutes and private companies have formed strong alliances to bring products with commercial and social benefits to market quickly.

The Australian Advantage

Nanotechnology is a thriving field of research, development and commercialisation in Australia. The country is renowned for its strong R&D credentials, innovative and highly skilled scientists, and enterprising workforce. Coupled with strong government support and strategic international alliances, Australian nanotechnology has delivered significant scientific breakthroughs that will have a lasting impact on our lives.

Invest Australia, the Australian Government's inward investment agency, promotes Australia's nanotechnology capability to the global marketplace and facilitates productive foreign direct investment into Australian industry. This document provides a capability overview of nanotechnology companies, commercial opportunities and fundamental research.

Nanotechnology is engineering at the molecular (groups of atoms) level. It is the collective term for a range of technologies, techniques and processes that involve the manipulation of matter at the smallest scale (from 1 nanometre to 100 nanometres).[1]

Australia has a reputation for scientific and technological creativity, and its powerful network of more than 75 nanotechnology research organisations and around 80 nanotechnology companies is ensuring a rich flow of commercial products.

The Australian Government provides valuable assistance towards developing a globally-focused nanotechnology capability through its 10-year *Backing Australia's Ability* strategy. The multi-billion dollar initiative ensures a steady stream of funding for scientific research and commercialisation. This funding is augmented by significant contributions from the state and territory governments and the private sector.

In May 2007 the Australian Government released its Industry Statement, *Global Integration*. The Statement announced funding for the establishment of a National Nanotechnology Strategy as well as funding for the development of niche manufacturing industries based on nanotechnology.

Research work in fundamental nanotechnology is quickly leading to applications across a range of industries. High-precision manufacturing techniques for constructing molecular structures are enabling stronger, smoother, more flexible, cheaper and smarter products. Products entering the market include advanced drug delivery methods, immunodiagnostic sensors, next-generation solar cells and energy storage devices, cosmetics and water treatment solutions.

Wide-ranging expertise

Much of Australia's nanotechnology research is undertaken at research institutions, universities, Cooperative Research Centres (CRCs), Centres of Excellence funded through the Australian Research Council, the Australian Nuclear Science and Technology Organisation (ANSTO) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Chris Skourtis, chemical engineer from the carbon nanotubes project team, examining a petri dish of raw carbon nanotubes. Image courtesy of CSIRO.

1 Prime Minister's Science, Engineering and Innovation Council (PMCEIC), *Nanotechnology – Enabling technologies for Australian innovative industries*, 2005

Australian nanotechnology research is focused on identifying commercial opportunities, bringing tangible products to market and solving concrete manufacturing challenges and on fundamental research. Areas of expertise include biotechnology, electronics, energy, environment, materials, photonics and quantum computing and quantum technology.

Global companies in every major industry have benefited from Australian nanoscience, from aeronautics (The Boeing Company, Airbus Deutschland GmbH, Hawker de Havilland) and information technology (Intel, Sony) to health (Merck, Pasteur Institute of France) and resources (Rio Tinto). The US Department of Defense's Advanced Research Projects Agency has also invested in Australian nanotechnology.

An example of collaboration across international borders is a project being undertaken by the Centre for Quantum Computer Technology. The Centre is looking at the fundamental physics and technology of building a solid-state quantum computer in silicon, and is collaborating with Hewlett-Packard Company, Los Alamos National Laboratories, Cambridge University and Harvard University. Its spin-off company Qucor Pty Ltd, which is commercialising the Centre's technologies, is partnering with the US National Security Agency, the US Department of Defense and major US technology corporations.

A smart investment location

Australia's reputation for nanotechnology excellence is built on its smart, industrious population, cost advantages, collaborative R&D network and strong industry and government support.

The Australian Government is supporting additional R&D investment in Australia by multinational enterprises through access to the 175% Premium Research and Development Tax Concession. Changes take effect on 1 July 2007 to extend access to the concession to companies which undertake their R&D in Australia but hold the intellectual property offshore. The initiative applies to additional R&D investment above the company's three year average.

The country is home to the most productive workforce in the Asia-Pacific region and the literacy of its people is ranked equal first in the world.[2] More than 30 per cent of the Australian workforce has tertiary qualifications and its skill base is replenished by an immigration policy attuned to the needs of industry. The proportion of foreign labour in Australia's economy is the third largest in the world.[3]

Many organisations have discovered that Australia is a cost-effective location to establish R&D facilities. In a recent survey of 128 cities in nine developed countries, Australia was ranked the second most cost-competitive nation. Business costs were lower in Australia than in Germany, Japan, the United States and the United Kingdom.[4]

Partnering for success

Government, industry, universities, specialist institutions and private organisations in Australia work closely to drive research into new products and processes. In 2004–05, business expenditure on R&D increased for the sixth consecutive year to A$8.4 billion.[5]

One example is the Nanotechnology Victoria (NanoVic) consortium. The consortium is a venture between Monash University, Swinburne University of Technology and RMIT University, and the CSIRO. In addition to university-based research, NanoVic manages a portfolio of commercial projects.

[2] IMD, World Competitiveness Yearbook 2006
[3] Ibid
[4] KPMG 2006
[5] Australian Bureau of Statistics, 2006

Another example is the Centre for Nanotechnology and Biomaterials at the University of Queensland, which is focusing on creating novel materials and devices for medical and diagnostic needs. The Centre is working with three prominent Seattle institutes – The Fred Hutchinson Cancer Research Center, the Seattle Biomedical Research Institute and the University of Washington – to develop cervical and breast cancer detection systems.

Fostering creativity with a strong R&D network

Australia boasts a number of R&D programs aimed at building the country's capabilities in nanotechnology and expanding its alliances with international organisations.

The Australian Research Council

The Australian Research Council (ARC) is an important vehicle for the Australian Government's funding of research across all disciplines (except clinical medicine and dentistry). The ARC aims to build research scale and focus, as well as strengthen partnerships in Australia and abroad, through funding for research projects, fellowships, networks and centres. The ARC currently funds more than 360 nanotechnology-related projects and has committed A$315 million for more than 700 projects since 1998.

The Council's Discovery schemes provide a variety of fellowships to nurture the talents of promising researchers and support established researchers. One of Australia's leading nanotechnology companies, Advanced Nanotechnology Limited, was established with funding from the ARC Discovery scheme. In 2006, more than 900 projects received Discovery funding.

The ARC Federation Fellowship program ensures Australia has a deep pool of skilled nanotechnologists by providing opportunities for Australian researchers to return to or remain in key positions in the country and to attract non-Australian researchers when appropriate. Up to 25 Federation Fellowships, which offer an internationally competitive salary and a standard tenure of five years, may be awarded each year.

Similarly, the ARC Linkage scheme provides funding to promote national and international partnerships between researchers and business, industry, community organisations and other publicly funded research agencies.

The Cooperative Research Centre

The Cooperative Research Centre (CRC) Programme is a research initiative unique to Australia. It encourages the commercialisation of cutting-edge research by bringing together researchers from universities, government laboratories, public sector research agencies and private industry in long-term collaborative arrangements.

The Programme has funded more than 158 activities to the tune of A$11 billion since 1990. This includes more than A$2.6 billion from the CRC Programme, A$2.8 billion from universities, A$2.1 billion from industry and more than A$1.1 billion from CSIRO. In December 2006, the Australian Government announced a further A$310 million in funding for 14 CRCs.

Major features of CRCs include a corporate management board and an emphasis on forming spin-off companies to commercialise R&D. One successful spin-off company is Ceram Polymerik,

Dragonfly and a UV-illuminated rod of crosslinked recombinant resilin. Resilin knot photograph by Dr David Merritt (UQ, Brisbane, Australia); Dragonfly image by David McClenaghan, CSIRO Canberra, Australia. Layout by Dr Nancy Liyou and Ted Hagemeijer.

CSIRO scientist examining a transparent sheet of polymer-based material, produced for "The Breathable Film for Fresh Food" project. Image courtesy of CSIRO

which uses polymer composites for passive fire protection. The world-first technology was first used by Olex Australia as insulation for its high performance fire cable.

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

CSIRO is Australia's national science agency and one of the largest and most diverse scientific research organisations in the world. It is the single largest employer of scientists in Australia, with more than 6,500 people conducting and assisting with scientific research at 57 sites in Australia and around the world.

The agency has undertaken work in more than 80 countries, partnering with governments, small companies, large multinationals, research institutes, universities, aid agencies and international foundations. More than 740 international research projects are undertaken by CSIRO each year.

CSIRO has expertise in a wide range of nanotechnology fields, including nanoparticles, nano-biotechnology, biomaterials, electronics, photonics, quantum computing and instrumentation. It has a track record of success, developing new polymers, new platforms for disease diagnosis, electrochemical capacitors and superconducting nanostructures.

CSIRO will be responsible for the Government's new Niche Manufacturing Flagship for the development of nanotechnology applications.

Australian Microscopy and Microanalysis Research Facility

The Australian Microscopy and Microanalysis Research Facility was set up under the Australian Government's National Collaborative Research Infrastructure Strategy in 2007. A joint venture between a number of universities, the facility provides a complete suite of instruments from pulsed laser local electrode atom probes to ultra-high resolution transmission electron microscopy (TEM) platforms.

Open, efficient regulation

Businesses that invest in Australia will benefit from one of the most effective and transparent regulatory systems in the world. Of the 30 OECD countries, Australia has been identified as having the fewest restrictions on product markets, the least public ownership of business and the least restrictive impact of business regulation on economic behaviour.[6]

The country is also the fastest place in the world to start a business, with regulatory procedures taking just two days.[7] In addition, there are no foreign exchange controls in Australia and the Australian dollar is now the sixth most actively traded currency in the world[8].

Australia's intellectual property legislation reflects international best practice, ensuring Australian-based firms benefit from the most comprehensive protection possible. The country's patent and copyright enforcement regime is ranked the second best in the Asia-Pacific region[9] and among the best six in the world, above the United Kingdom and the United States.

[6] OECD 2007
[7] World Bank 2006
[8] Bank for International Settlements, *Triennial Central Bank Survey*, 2004
[9] IMD, World Competitiveness Yearbook 2006

Materials

Australia's expertise in materials, particles and coatings nanotechnology has produced a wide variety of products with applications in a range of industries. These include extremely hard, antibacterial, antiviral and smooth coatings for industrial tools; enhanced paints and glass; prosthetics; and membranes used for energy production and storage and pollution control.

The consumer products industry has taken advantage of Australian nano-materials and coatings technology to manufacture a range of highly functional consumer products that offer fade, heat, water and spill resistance, biocompatibility and novel cosmetic and sun protection qualities. Other beneficiaries include the textiles, coatings and cosmetics industries.

Acme Nano Products Pty Ltd researches and supplies patented nanoclays to industry. The unique nanoclays are mixed into existing products that provide benefits such as anti-bacterial and gas barrier properties to UV and heat resistance. The nanoclay particles (platelets) form an ionic bond with the product, allowing them to remain in suspension. This makes them ideal for any liquid product with a long shelf life. Acme Nano Products collaborates with researchers to develop solutions for its customers and partners in the cosmetic, plastic, paint and ceramic industries.

Advanced Nanotechnology Ltd produces a range of nanoscale powders as small as five nanometres in diameter. The company has built on research by the University of Western Australia to commercialise a patent-protected, solid-state mechanochemical nanopowder manufacturing technology (MCP™). MCP™ enables the production of a broad range of nanopowders for cosmetics, coatings and films, healthcare, catalysts and advanced ceramics. Initial products include transparent zinc oxide for UV protection, nanoplatelet alumina powders for cosmetics, and nanocerium oxide dispersions for environmental applications.

Advanced Nanotechnology is progressively increasing its suite of products while developing breakthrough applications in the areas of personal care, functional materials and advanced ceramics. In particular, the company is pursuing opportunities in transparent functional coatings.

Advanced Nanotechnology has numerous international partners and clients. Samsung Corning (a joint venture between the Korean and US industrial companies) was an early investor after being attracted by opportunities to use the particles in the electronics industry for polishing microchips. Advanced Nanotechnology is also working with UK-based Oxonica Limited to produce a transparent cerium oxide fuel catalyst. Further applications have been found in the building industry, with Advanced Nanotechnology's nanoZ® transparent zinc oxide material providing UV protection in Bondall Paints. Advanced Nanotechnology's ZinClear® product provides a similar benefit in numerous sunscreen cream brands. Its aluminium oxide product, Alusion™, is being used by the world's leading cosmetics companies to improve the texture and adhesion to their make-ups and anti-ageing products.

In 2005, Advanced Nanotechnology was awarded the global Frost & Sullivan Excellence in Technology of the Year Award in Nanomaterials. In 2006, Lux Research named Advanced Nanotechnology on its list of Most Well-Rounded Nanotechnology Start-Ups.

With operations in Australia, Malaysia and Thailand, **Asia Nanomaterials Pty Ltd** provides research and development to small and large businesses in nanotechnology and materials science. Its R&D expertise includes production and applications of nanoparticles and nanocomposites, biomimetic materials and nanotoxicology within the manufacturing sector. Asia Nanomaterials' expertise includes technological disruption issues and sustainable processes within the chemicals and manufacturing sectors.

The **Department of Applied Mathematics** at the **Australian National University** has established expertise in the measurement of dynamic interactions of confined fluids using adaptations of the Atomic Force Microscope. The properties of highly confined fluids, single molecules and molecular assemblies can be probed on the nanometre level at a range of frequencies. Elasticity, viscosity and flow boundary conditions are studied. Such knowledge is of fundamental interest and is important in understanding the flow of liquids in highly confined systems such as some microfluidic systems.

The **Department of Electronic Materials Engineering (EME)** at the **Australian National University** conducts interdisciplinary research in areas such as condensed matter physics, materials science, nanoscience and nanotechnology. The properties of nano-scale materials and the ability to understand, fabricate, manipulate and use such materials is a critical area of research for the Department. One project is researching carbon and boron nitride nanotubes. Carbon nanotubes are tiny cylinders of graphite sheets with a diameter of a few nanometers. Growth of aligned and patterned carbon nanotubes is an important step towards the fabrication of nanotube electronic devices on a large scale. The project aims to investigate the growth of aligned carbon nanotubes on pre-patterned silicon wafers using a mechanically activated chemical vapour deposition method.

Boron nitride (BN) nanotubes have the same atomic structure as carbon nanotubes but have many interesting properties, including a more stable electronic property and better resistance to oxidation at high temperatures. EME has developed a unique ball-milling and annealing process that can produce large-quantity and high-yield BN nanotubes and the team has established the first commercial source of BN nanotubes in the world. EME is a major supplier of commercial BN nanotubes.

Another project is investigating one-dimensional (1D) nanorods and nanowires with a diameter less than 100 nm. These are a new class of nanomaterials with new or modified material properties due to electron confinement and high-surface-area effects. The single crystalline structure and high surface-to-volume ratios of the 1D nanomaterials endow them with high stiffness, strength and other new mechanical properties, which lead to applications in reinforced composites, nanosized actuators, force sensors and calorimeters. The new chemical, electronic and magnetic properties of nanowires and nanorods have a vast range of uses in electronic, sensing and catalytic applications. A large range of nanowires and nanorods of different materials including pure elements (Si, C and Zn), oxides (ZnO, SiO and AiSiO), and nitrides and carbides (BN, SiN and SiC) have been made at EME using the ball-milling and annealing method. Only thin films of nanowires and rods are produced using common chemical vapour deposition methods, where as the nanowires produced at EME are in a loose and free-standing form and are produced in much larger quantities, suitable for broad-range and large-scale applications.

Neutron and X-ray scattering methods have been developed by the **Research School of Chemistry** at the **Australian National University** to study the structure and dynamics of nanometre and picosecond space/time scale. Adsorption, self-assembly at interfaces, polymers, the imitation of biomaterialisation phenomena using template molecules and the structure and denaturation of proteins at interfaces are current research projects. The School has determined the thermodynamic parameters from protein denaturation in the 50 Å surface layer of a protein solution. In another project, it has measured the interfacial structure of an emulsion surface by neutron reflectivity and has extended this work to include new surface design. This research has been undertaken for Orica (Australia) Limited and Food Science Australia.

Other research undertaken involves the development of methods and strategies to measure, interpret and analyse diffuse X-ray (and neutron) scattering to enhance the detailed understanding of the relationships between structure and properties in all kinds of materials and help promote the design of new materials. Of key importance is the investigation of the role played by local strain in determining the nano-scale structure of disordered materials.

The University is researching a range of non-stoichiometric inorganic materials with a view to understanding how the complex disorder present is of importance in explaining their physical properties (for example, ferro-electricity, ferro-elasticity, ionic conductivity and etc.). Included in this category is a number of important ceramic materials such as stabilised zirconias, wüstite and mullite.

In collaboration with ISIS in the UK, the University has undertaken research into the study of diffuse scattering in the relaxor ferro-electric material PZN. It has developed a model for PZN that explains the diffuse scattering that is observed and is based on the supposition that the origin of its properties is the lone-pair electrons of the Pb atoms.

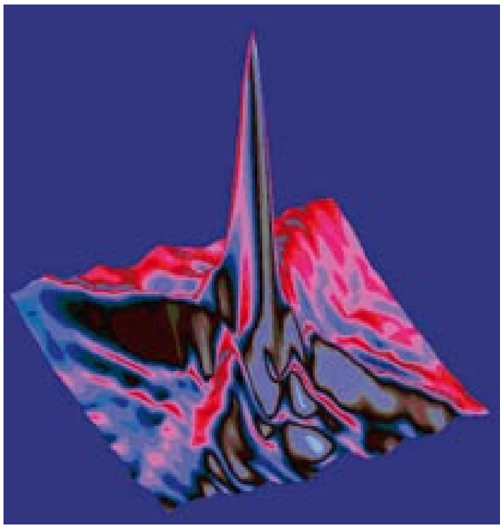
Researchers at the **Australian Research Council Centre of Excellence for Functional Nanomaterials** at the **University of Western Sydney** are working on three fundamental areas in nanotechnology research: nucleation and growth of carbon nanotubes (CNT), polymer-clay nanocomposites and carbon nanotube functionalisation. The electronic structures of carbon nanotubes depend strongly on diameter and chirality. To date, no-one has been able to produce a single kind of CNT. This is a serious limiting factor in fundamental nanotube metrology and commercialisation of carbon nanotube-based electronics.

The Centre's researchers have been investigating and manipulating the catalytic particle's fine structure, which may allow the development of new strategies for the fabrication of CNTs with controlled electronic properties. The success of this research program will boost the technological advancement in the area of nano-electronics and carbon-based computing.

Researchers are also developing fast and efficient procedures for the covalent functionalisation of fullerene C60 and carbon nanotube using microwave radiation. Their current research shows that the microwave functionalisation can be extended to realise the mono-functionalisation of the CNTs with other nanostructures, all in a single processing step. This finding should lead to fast and inexpensive processing to produce functional CNTs, which is extremely important for their use in carbon nanotube-polymer nanocomposites. The researchers will synthesise CNT-polymer-based nanocomposites and will investigate the CNT/polymer matrix interface and the chemistry of the interface.

The **Centre for Advanced Manufacturing Research** at the **University of South Australia** has developed innovative methods to self-assemble polymeric nano composite materials, which can be used for medical, automotive and mineral applications. Researchers are studying molecular and nanoparticle interactions to develop a fundamental understanding of assembly processes. Its technology can also be applied to desalination processes.

The **Centre for Materials and Surface Science** at **La Trobe University** is an interdisciplinary research group with interests in the development of advanced composite materials incorporating carbon nanotubes; investigation of metal forming and the role of lubricants; application of functional coatings on industrial polymers; molecular interactions at surfaces; surface modification and ageing of polymers; synchrotron-based characterisation of materials using electronic, compositional and structural techniques and the development of unique instrumentation; creation and interrogation of novel X-ray optical structures using micro- and nanofabrication and synchrotron techniques; semiconductor growth by molecular beam epitaxy; fabrication of micro-patterned biodiagnostic structures using soft lithography and electrochemical techniques; surface science of paper; characterisation of protein uptake on resins; surface chemistry of bacteria and immobilised DNA; and environmental surface chemistry including remediation and ion transport issues.



X-ray Light. Image courtesy of La Trobe University.

The Centre collaborates with or provides analytical services to 15 Australian and international universities, three divisions of CSIRO (Commonwealth Scientific and Industrial Research Organisation), the Defence Science and Technology Organisation (DSTO) and around 30 Australian and international companies. It has key roles in and partnerships with the Australian Research Council Centre of Excellence in Coherent X-ray Science, the Victorian Centre for Advanced Materials Manufacturing, the BESSY Synchrotron in Germany and the Australian Synchrotron.

The Centre has extensive, world-class characterisation infrastructure, including X-ray photoelectron spectroscopy (XPS), time-of-flight secondary ion mass spectrometry (TOF-SIMS), photoelectron spectroscopies, X-ray micro-tomography, optical contact angle analysis, scanning probe microscopy, optical microscopies and a variety of synchrotron-based resources.

The **Centre for Strategic Nano-Fabrication (Incorporating Toxicology)** at the **University of Western Australia** focuses on continuous flow processing technologies based on rotating surfaces. The Centre can prepare nanoparticles of uniform size distribution for a diverse range of materials and tailored to meet industry and consumer specifications. The materials include metals, inorganics, organics and composites. The technology allows it to control the size, shape, surface, agglomeration, phase and defects of the nanoparticles. In addition, it allows nanoparticles to be coated with other materials.

The Centre's core business is nanotoxicology and the impact of nanotechnology on the environment (sustainability metrics), making products attractive to industry, safe and acceptable to the community. The technology allows more efficient processes, minimising energy use and simplifing scale-up requirements; indeed, the research reactor can be the production reactor.

Current research projects include the synthesis of nanoparticles and nanohybrids using rotating surfaces, including light harvesting nanoparticles; superparamagnetic nanoparticles in magnetic resonance, contrast enhancement, tissue repair, detoxification of biological fluids and drug delivery; testing nanoparticles for effects on healthy cells in culture as an initial screen protocol for toxicity; nanoforensics; nanocatalysis for the fine chemical industry; and new generation technology. The Centre collaborates with a range of companies including AGR Matthey, CleanTeq, Dyesol and Protensive.

The **Cooperative Research Centre for Advanced Composite Structures (CRC-ACS)** brings together universities, government laboratories and industry partners to conduct R&D into the design, manufacture, testing, durability and support of composite structures. The CRC-ACS head office is located in the Defence Science and Technology Organisation's site. There are also offices in Hawker de Havilland sites in two Australian cities and plans to establish a new research centre in collaboration with Australian Aerospace.

Highly skilled experts at CRC-ACS work with industry to develop new technologies to improve the cost-competitiveness and structural performance of composite materials. Core research capabilities of CRC-ACS include design and analysis, including impact and energy absorption; manufacturing process development and modelling; resin infusion technology; Structural Health Monitoring (SHM); and pultrusion, hybrid joints and fire protection.

CRC-ACS has signed a number of research agreements with leading aerospace companies, including The Boeing Company and Airbus, and was instrumental in developing technologies for Hawker de Havilland to win work on the Boeing 787 program. These technologies included diaphragm forming, unitised construction, process simulation, postbuckling design, design optimisation, bird-strike simulation and liquid moulding.

A CRC-ACS joint project with RMIT University and Airbus Deutschland GmbH on composite defect modelling won the 2005 Australian Business and Higher Education Round Table (BHERT) Award for Best International Collaboration – Research and Development.

In nanotechnology, CRC-ACS is working with several of its participants, including CSIRO, the University of New South Wales and the University of Sydney, to evaluate the potential advantages nanoscale particles can give to advanced composite structures, in particular for the aerospace industry. Through the incorporation of nanoparticles into high-performance epoxy resins, improvements to the fire resistance of composite structures may be achieved.

Nanoparticle reinforcement is also being investigated for the production of stronger high temperature joints on structural components through the development of improved adhesives or for increased bearing strength. The work with university partners is also focused on developing a scientific understanding of the mechanisms by which nanoparticles can improve the performance of their host material. More recently, CRC-ACS has begun work with NanoVic to identify commercial uses for nanotechnology within advanced composite structures.

The **Cooperative Research Centre for Functional Communication Surfaces**, also known as the **CRC Smartprint**, operates its corporate office from Monash University. The CRC has four research nodes: the Australian National University, CSIRO (Ensis), Monash University and the University of Wollongong. The Centre is engaged in conducting pure and applied research into various aspects of printing, including printable materials, printing processes and materials used within the industry. Among the 20 research projects being conducted into the mechanisms of printing processes, the enhancement of substrates and the recycling of printed materials. The CRC is progressing research into functionalised nanoparticulate materials that can be used in the surface coatings of paper and printable materials to act as 'colour traps' for the dyes that are used in ink-jet ink formulations. The research is aimed at producing a cost-effective formulation that can be applied to the surface of multi-purpose office paper during its manufacture, which enhances ink-jet colour reproduction but does not alter other characteristics of the paper.

The **Cooperative Research Centre (CRC) for Polymers** is developing specialty polymers for a wide range of applications in the biotechnology, manufacturing, mining, agricultural and energy sectors. It conducts research in four key areas: biomedical polymers, advanced polymeric materials, polymers for sustainable development, and engineering and design. Participants in the CRC include 10 universities, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australian Nuclear Science and Technology Organisation (ANSTO), 10 companies and the Australian Stem Cell Centre.

The Centre's research on advanced polymeric materials for use in manufacturing involves developing polymer-based materials that are nanoengineered for specialty applications by controlling the microenvironment around compounds or nanoparticles in a polymer matrix. This will result in the development of additives for polymer toughening, novel materials for data storage and photochromic dyes with tailored rates of fade in polymer matrices.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) is using its world-leading expertise in innovative design of multifunctional nanoparticles, surface/interface molecular design for the nano-dispersion and tailoring of nanocomposite composition to develop a range of polymer nanocomposites. Products and technologies that have been, or are being, commercialised include nano-engineered surfaces for improved adhesion; UV-resistant nano- coating for beer bottles and wood finishes; fire-resistant nanocomposites and coatings; nanomaterials for barrier packaging; electrical conductive nanocomposites and coatings; and impact-resistant composite laminates.

The Boeing Company is one of the major groups now partnering with CSIRO in the development of high-performance plastics for use in the next generation of aeronautical materials. Other partners include ACI Packaging, Ansell, Bottle Magic, CAP-XX, Hawker de Havilland, Laserlite, Micronisers, Orica and Piber Plastics. CSIRO is also developing viable alternatives to petrochemicals with naturally derived fibres, fillers and polymer resins for producing bio-based nanocomposites that are combustible, compostable, renewable and carbon-dioxide neutral.

CSIRO has strong capabilities in the design and fabrication of nanoparticles and has achieved success in commercialising their use in a wide range of products such as plastic additives, textile coatings, paints and varnishes and personal care products, and has done this in collaboration with companies such as Micronisers and Bottle Magic. These capabilities have been leveraged in the design, synthesis and characterisation of multifunctional nanoparticles that possess more than one functionality in terms of barrier property, flame retardant, electrical/thermal conductivity, antimicrobial, UV-resistant and infrared-heat reflectance. This means that it is possible to reduce both the amount and the type of nanoparticles that are currently being used for the development of multifunctional nanocomposites, resulting in high-performance materials being developed at a reduced cost with enhanced functionalities, easier processing and a lighter weight.

Nano-engineering in aluminium alloys involves designing precipitate species, manipulating their distribution through design of the heat-treatment cycles and tailoring their mechanical characteristics. This produces attractive mechanical and functional properties in high-strength aluminium alloys that can be used in automotive and aerospace applications.

CSIRO is working on a number of products and applications for the technology that include high

Carbon nanotubes being 'spun' to form a yarn. Image courtesy of CSIRO.

performance nanoengineered aluminium alloys exhibiting 500–800 per cent higher energy absorption capability than conventional aluminium alloy; high-pressure diecastings with more than 100 per cent increase in strength; nanoscale dynamic precipitation in Al-Cu-Mg-Ag alloy to meet design criteria for next-generation supersonic transport such as very low creep strain; and the creation of self-healing metal structures during fatigue.

In partnership with the University of Texas, Dallas, a team from CSIRO has created and patented a new range of dry-formed carbon nanotube structures, including 'forests', yarns and 'sheets'. The partners maintain the international lead in the controlled production of these structures. These carbon nanotube structures offer myriad applications in many sectors, including aerospace composites, electronics and membranes for gas and hydrocarbon separation and water purification.

A CSIRO team has developed an understanding of the effect of incorporating nanoparticles into polymers during melt extrusion of fibres. It now understands how parameters such as the type and degree of crystallinity are affected by the addition of different nanoparticles and the relationship between these parameters and processing, particularly the effect of drawing of polymer fibres and the impact on final fibre properties has been determined. Polymer fibres incorporating nanoparticles have potential applications where high-strength, high-toughness or improved fire-resistant properties are required.

CSIRO's capability in emulsion formation and stability of nanoemulsions/capsules provides a platform technology for a robust nanoencapsulation system – stable nanodroplets and nanocapsules that will enable the stimulated release of functional bioactive ingredients. Applications for the platform nanoencapsulation technology include encapsulation of health-giving bioactive ingredients, the incorporation of clear nanoencapsulated bioactives in beverages, the targeted release of bioactives within the digestive system, and uses in non-food applications such as the encapsulation of agricultural herbicides and pesticides for delivery of minimal effective dose, thus reducing residue levels in plant, foods and the environment.

Flinders University is researching applications with polymers; sol-gel, POSS and other silicon-based materials; single molecule magnets; nanocomposites; FRET quantum dots; liquid crystals; dendrimers; biosensors; carbon nanotubes; thin films; surface technologies and bio-devices. Many of these processes have direct industry applications in health, environmental management, food and wine and advanced manufacturing. The University is working with CSIRO (Commonwealth Scientific and Industrial Research Organisation) to develop a clay nylon filter, that will have the barrier properties of nylon but with decreased flammability. Other projects include research into stopping polyurethane thin films from blistering, attaching carbon nanotubes to gold surfaces as sensors, developing light receptors to separate charge, lining nanotubes along an array to make a nanowire or a grid network, and combining quantum dots and FRET-bioconjugates to form molecular capsules for drug delivery. Working with Vinpac International, Flinders University has developed a way to stop corks tainting wine which will have economic benefits for the wine industry.

Flinders University's Nanomaterials Group focuses on polymers and surfaces, generating new research into sol-gel and polymer chemistry, bioconjugates, catalysis and silicon chemistry. The Group is working with the Australian Nuclear Science and Technology Organisation (ANSTO), Flinders Medical Centre and Monash University to create new nanocomposites for various applications – for instance, by modifying the outer layer of multi-walled carbon nanotubes, improvements in polymer nanocomposite strength, thermal conductivity and field emission properties have been achieved.

Flinders University's Smart Surface Structures Group's projects cover surface-immobilised size-selected clusters; fabrication of a new glucose biosensor; controlling molecular self-assembly processes; functionalised carbon surfaces (graphite and nanotubes) with plasma enhanced CVD; determination of the adsorbate adhesion energy of surface-bound species; and organo-silicon-based corrosion protection coatings.

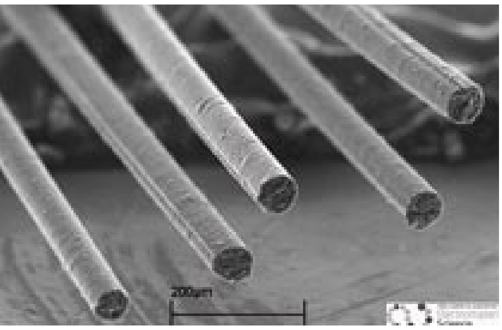
G.James Australia's Architectural Glass division manufactures and markets a range of laminated products that incorporates a 'bonding' inter-layer that contains nanoparticles of lanthanum hexaboride. These nanoparticles have the unique ability to selectively reject heat while still allowing visible light to pass through, making these products ideal for commercial and residential glazing applications. An example of this type of glass features on the western façade of the recently completed Deutsche Bank Place in Sydney. G.James operates Australia's only glass-coating facility where large-area nanoscale metal and metal-oxide coatings are applied to glass destined for projects where the control of heat flow is required. The G.James Glass division is actively involved in product development using nanoscale materials in its own laboratory as well as working collaboratively with external research organisations.

The **Ian Wark Research Institute (The Wark™)** at the **University of South Australia** is the **Australian Research Council Special Research Centre for Particle and Material Interfaces**. It is also the headquarters of the Australian Mineral Science Research Institute (AMSRI), a virtual institute embracing research teams at the University of South Australia, the University of Melbourne, the University of Newcastle and the University of Queensland. The Wark™ conducts research on minerals and materials; its underlying theme is particle and material interfaces.

With internationally competitive research strengths, The Wark™ works with overseas researchers to develop new products from nano and biomaterials. It has world-leading research capability and a proven ability to disseminate research outcomes to Australian industry and the community for commercial and strategic benefit. The research program is supported by postdoctoral staff from Germany, India and Canada. It is supported by six Australian companies, Monash and Sydney Universities, and nine European laboratories: University of Bristol, UK; Abo Akademi, Finland; Swiss Federal Institute of Technology, Switzerland; Saarland University of Technology, Switzerland; Lulea University of Technology, Sweden; University of Ulm, Germany; Max Planck Institute for Colloids and Interfaces, Germany; and the Royal Institute of Technology, Sweden.

The Wark™ conducts a blend of fundamental and applied research across a broad range of industry sectors and research areas including: minerals processing; interparticle forces and adhesion; wetting and particle adsorption; nanotechnology and nanolubrication; biotechnology; bio and polymer interfaces; biomedical and biodental implants; pharmaceutical; metals; ceramics; composite materials; surface modification and coatings; surface engineering; molecular modelling; computational colloids; food; pigments; and the environment, including mine site remediation.

A key focus of current research is to add value to existing materials by applying coatings and surface modifications. The Wark™ has developed microwave plasma coating processes that can coat polymers and metals with uniform, transparent polymeric films with the outstanding ability



Carbon Nanotube Bio-Fibers containing Hyaluronic Acid. Image courtesy of Intelligent Polymer Research Institute

to protect materials against scratching, environmental stress crazing and abrasion. The process has been scaled up to a pilot stage. Markets include aircraft windows, automotive and marine plastics, for example, windows of boats and yachts currently fog rapidly due to salt spray. The Wark™ microwave plasma coating is expected to enhance the resistance to such damage.

With over 100 active research projects, major clients include Anglo American Platinum Corporation, BHP Billiton, Bridgestone Australia, Cytec Industries, Kodak, MIM Holdings, Newcrest Mining, Newmont Australia, Philips National Research Laboratories, Rio Tinto, Schefenacker Vision Systems Australia, Sola International, Teck Cominco, Unilever and WMC Resources.

An interdisciplinary team at the **Institute for Nanoscale Technology** at the **University of Technology, Sydney** is developing self-assembling systems for making optically active composite nanomaterials and devices. It is also researching applications for 'smart' coating materials such as vanadium dioxide. Prototype samples can be produced by physical vapour deposition and conventional powder chemical means.

The Institute is investigating the industrial applications of precious metals in general, nanolithography, molecular modelling and advanced materials. Other material projects address super-hard nanograined coatings, equal channel extrusion technologies, ceramic materials and surface coating technologies for improving the performance of prosthetics and implants.

The **Intelligent Polymer Research Institute (IPRI)** at the **University of Wollongong**, together with partners at Monash University, Bionic Ear Institute and St Vincent's Health, has received an Australian Research Council Centre of Excellence for Electromaterials Science Award. IPRI researches materials in the nano domain where electronic conductivity is vastly higher than in larger structures. The Institute is investigating the generation of nanostructured electroactive fibres using various processes. For example, solutions of appropriate constituents, concentration and rheology are wet-spun or electrospun to produce high tenacity, conducting fibres with applications ranging from electronic textiles to artificial muscles.

IPRI is working with the Centre Nationale de Recherche Scientifique in France to investigate the interactions of carbon nanotubes with biological molecules and developing wet-spinning methods to produce carbon nanotube bio-fibres. These fibres can be used for nerve cell regrowth and wearable prosthetics. IPRI is also developing methods to produce polyaniline-carbon nanotube fibres that demonstrate an order of magnitude increase in stress capabilities for artificial muscles. The Institute has strategic links and alliances with other research institutions in France, Ireland, Italy, Japan, Korea, the UK and the US. It also has a network of partners to commercialise its applications.

KingGee supplies a wide range of work clothing for most industries and job functions, from industrial through to corporate wear. KingGee has incorporated nanotechnology into its clothing ranges using a process in which the molecules bind to the fabric's fibres causing them to be spill resistant. This treatment makes the fabric liquid repellent and stain resistant without altering the fabric's feel or ability to breathe.

Lu Papi and Associates, working with Sandvik's materials technology division in Sweden, has developed the technology and capability to bend Sandvik's NanoFlex tube. Lu Papi and Associates has designed and built special bending tools and annealed the NanoFlex before bending and reheating to restore the technology's full properties. The company's research and development achievements will allow Sandvik-Precitube in France to produce more commercially viable NanoFlex products. Lu Papi and Associates is using NanoFlex to develop a superior wheelchair frame that is light (less than 5.5 kg), corrosion-proof and free of a rear axle.

The **Department of Physics** at **Macquarie University** has long-term expertise in the growth of semiconductor nitride materials that has led to the public listing of **Bluglass Ltd**, which develops gallium nitride (GaN) light emitting diodes (LED) sources on silica and other substrates. The Department is developing new research programs on organic semiconductor and rare-earth nitride material physics and enabling diamond chemical vapour deposition technology. Diamond has many desirable properties, such as high hardness, wide bandgap, bio-compatibility and high thermal conductivity, which make it ideal for use in a wide range of nanotechnology applications from bio-labelling to quantum information processing.

The **Microelectronics and Materials Technology Centre (MMTC)** at **RMIT University** is developing a range of nanostructured materials. Thin films with nanopores, nanowires and nanorods are being developed for surface acoustic wave gas and biosensors with enhanced sensitivity. It is also developing ferroelectric materials for use in novel tuneable microwave devices and using soft lithography to replicate films with nanoscale features in polymer.

Micronisers Pty Ltd specialises in advanced milling and chemical processes to produce products at the molecular level. The company also provides excellent production facilities and technical support for customers wishing to have proprietary products manufactured to specific requirements for particle size, distribution and encapsulation.

Working in conjunction with CSIRO (Commonwealth Scientific and Industrial Research Organisation), Micronisers has developed a unique process for the cost-effective manufacture of commercial quantities of 30–50 nm nano zinc oxide. The process has been modified to also produce a nano-sized nucleating agent for crystalline and semi-crystalline polymers, such as poly propylene and nylon. The nano-sized zinc oxide is transparent and can be used to protect the skin from ageing and cancer (Nanosun); textiles from fading (Nanocryl); and plastics, outdoor furnishings and timber from unsightly physical degradation (Microsun) caused by the damaging effects of the sun.

Micronisers has specialised knowledge and processes for the coating and dispersion technology needed to ensure the nanoparticles provide all the potential benefits for customers. The company has agreements with a number of international companies to further develop the applications and efficiency of nano zinc oxide to provide a safe and effective barrier to both UVA and UVB in local and overseas markets. It has potential applications for colourfast plastics, superior skin protection and enhanced fabric protection with multifunction benefits.

Micronisers is exploring the application of its unique manufacturing process for the production of a range of nanoparticles for use in agriculture. The patented nanonucleating agent (Microstat) is used to improve the structural strength of polymers, while increasing productivity by up to 30 per cent with less wastage, recycling and improved clarity. Additional research and development is underway to further increase the efficiency of this new product and provide plastic processors with unsurpassed performance.

Nanoprotect® CS causing the water beading water on the stone. Image courtesy of Nanotec Pty Ltd

The **Nanoscale Science and Technology Centre (NSTC)** at **Griffith University** has expertise in the fundamental theory of materials, materials development, sensing, microelectronic engineering and microtechnology across the disciplines of physics, chemistry, biology, mathematics and engineering. NSTC investigates problems integral to the development of intelligent systems for the coming revolution in nanotechnology. These include the development of new sampling and sensing devices, next- and future-generation electronics and advanced functional materials, as well as gaining a better understanding of the fundamental nature of nanostructures and the 'micro-meets-nano' (M@NT) issues of scale. The Centre must address these latter issues as it progresses from microscale to nanoscale devices and systems.

NSTC has research programs and opportunities for industry linkage projects in nanostructures (the theory of nanostructures, mining nature, templating, nanowriting, hydrogen storage materials, nanomagnetism and spintronics); nanosensors (functionalised nanotubes for sensing applications); nano/microelectronics (silicon carbide (SiC) devices and silicon oxide (SiO_2) devices); nano/microfluidics; and Lab-on-a-Chip (analyte manuipulation and nanofluidics theory). A current priority is developing sensors for hazardous materials based on carbon nanotubes functionalised to confer chemical selectivity. NSTC is already equipped to modify carbon nanotubes, fabricate microelectronic devices and integrate these as a Lab-on-a-Chip package.

Nanotec Pty Ltd was founded in 2003 as a developer, marketer and distributor of surface protection treatments using advanced nanotechnology. The company collaborates with leading nanotechnology research and development organisations around the world to provide customers and partners with formulated treatments for unique and individual requirements.

Nanotec offers a broad range of nanotechnology-based surface treatments for building, paving, automotive, marine and textile applications, which are marketed under the Nanoprotect®, Nanoprotex® and Nanoseal® brands. These products change the structure of the surface they are applied to at the molecular level, using charged particles in a carrier liquid, such as water or alcohol. The treatment is sprayed on the surface and the carrier evaporates, leaving an invisible protective layer approximately five atoms thick.

The company's products are non-toxic, environmentally-friendly, easy to handle, UV stable, water repellent, dirt and oil deflecting, moss and algae rejecting, and weather and friction resistant. They provide an economical, long-lasting, easy-cleaning effect that saves time and money, and has a broad range of industrial, commercial and domestic applications.

Nanotechnology Victoria (NanoVic) was formed as a consortium dedicated to the industrial exploration of nanotechnology. Founding members include Monash University, RMIT University, Swinburne University and CSIRO (Commonwealth Scientific and Industrial Research Organisation). NanoVic also works with a variety of other research providers across Australia. NanoVic has conducted more than 60 projects in the last three years, and established relationships with many of Australia's leading technology-based corporations.

NanoVic's nanopigments project aims to develop pigments based on intercalation of dyes into nanoclays. This gives a colourant with enhanced properties including UV resistance, thermal stability, transparency and low migration. It is also developing a method of depositing carbon nanotubes onto glass fibre reinforcement for applications in ballistic protection panels and light- weight consumer goods. The consortium's materials team has been active in glass coatings and has formed an association with glass manufacturer Pilkington Australia to develop coated glass technologies.

Approximately 30 smaller projects have been undertaken in collaboration with companies to demonstrate the use of nanotechnology in antibacterial materials, corrosion resistance, EMI shielding materials, forensic technology and magnetic fluids.

Novel Laser Technologies (NLT) possesses technology and accompanying intellectual property that, for the first time, permits the deposition of ultra-thin diamond coatings on any substrate at room temperature. In the past, diamond coatings could only be deposited on substrates that were able to withstand temperatures of at least 400°C. The unique, room-temperature diamond deposition features of NLT's technology make it possible to diamond-coat a wide range of new and useful substrates, like thin silicon wafers, glass, plastics and metals with low melting points such as copper and aluminium.

Diamond produced using NLT's technology is 100 per cent pure and, like natural diamond, is electrically insulating. However, using the same generic technology, a diamond coating can be doped to produce a desired electrical effect. In this way, for example, the diamond produced can form the basis for a new family of diamond-based semi- and super-conductors; that is, new electronic devices capable of operating under high temperatures.

NLT's diamond coatings have other potential uses, including high frequency/high power transistors, electron and light emission, radiation sensing, light detection, pressure sensing, temperature measurement, magnetic field measurement, X-ray windows, IR windows and thermal propagation.

For more than 10 years, the consumer products research group at Australian chemical company **Orica Ltd** has built up monomers into latex particles of 80–100 nm in diameter for use in paint products. Orica's patented Dulux brand Wash & Wear 101 Advanced product uses specially formulated nanoscale polymer latexes. The company is also using nanoparticle zinc oxide from Micronisers Pty Ltd to add transparent UV protection to its Intergrain branded exterior wood finishes.

Orica has been working with the Key Centre for Polymer Colloids at the University of Sydney for four years on the development of new forms of nanoscale latexes for paints and adhesives. This work focuses on building polymer latexes one molecule at a time to maximise performance and minimise cost. The company plans to commercialise these products in the next two years.

The **Queensland University of Technology** is investigating the deformation and failure of magnesium-based nanocrystalline and zirconium-based amorphous alloys using mechanical testing and advanced microanalysis. Interest in the development of advanced materials has increased as a result of microstructural refinement and structure modification through the formation of nonequilibrium phases (amorphous, quasicrystalline and nanocrystalline) due to their superior mechanical, magnetic and electronic and transport properties. These developments emphasise the need to explore, at a fundamental level, the progress associated with deformation and fracture of nanocrystalline and amorphous metals.

Major enhancements in mechanical, rheological, dielectric, optical and other properties of polymer materials have been achieved by adding various nano inorganic particles and fillers. Nanofillers such as nanotubes, silica beads and cages, clays and inorganic oxides (TiO_2, SiO_2, Al_2O_3) offer phenomenal advantages over more traditional fillers because greater property improvement can be achieved with far less material. The University has successfully fabricated and characterised rubber-toughened epoxy and nylon66/clay nanocomposites. This has resulted in significant improvements in mechanical properties.

The effect of water beading after a cement sheet is treated with Nanoprotect® CS. Image courtesy of Nanotec Pty Ltd

The **Rheology and Material Processing Centre** at **RMIT University** specialises in polymer processing, slurries and multi-phase mixtures. Its research covers co-continuous lamellar nanostructures to develop compounds with specific combined properties of toughness, stiffness and permeability in a combination that is not available in a single homopolymer and chaotic blending of nanocomposites to build several laminae. The Centre's other projects include the use of smectic clays to reinforce plastics and nanopigments with better ultraviolet (UV) resistance and thermal changes for use in the plastics, textile, paints, coating and ceramics industries.

Rio Tinto is conducting research and development in partnership with a range of Australian universities. The company is investigating areas where nanotechnology may be applied to its mining operations. With the University of New South Wales, Rio Tinto is investigating the cleansing ability of TiO_2 to remove organics in aqueous liquors and from gases, particularly for reducing odours. Other areas of interest include developments in sensor technology that can detect poisonous gases and transmit information deep underground; clothing that can monitor the health of workers; processes to recover waste heat and convert it into energy; the development of membranes for water treatment and carbon sequestration; and micro-fluidics. Research partners include the University of Nottingham, in the UK, the University of Melbourne, the University of South Australia and the Ian Wark Research Institute. Rio Tinto has patented a nano- engineered gold-attracting polymer developed at the University of Wollongong.

The **School of Applied Sciences** at **RMIT University** is working with the BlueScope Steel Institute at the University of Wollongong and BlueScope Steel Ltd to develop nanoscale modifications of paint surfaces to aid in contamination resistance. This research involves the creation of atomistic models to gain a better understanding of the interaction between carbonaceous contaminants and polymer surfaces. Researchers are also creating simulations of novel coatings, including diffusion and self-stratification of additives with potential contamination resistance properties.

RPO Pty Ltd designs and manufactures optical polymers and application-specific polymer optical waveguides for consumer electronics applications. The company has dual technology platforms in materials technology, Inorganic Polymer Glass™, and waveguide fabrication technology, Advanced Polymer Integrated Optics™. RPO's intellectual property rights for this innovative technology are patented and the company is now focusing on markets for both platforms. It has partnered with the several investors to commercialise its technology, including GE Commercial Finance (US), BASF Venture Capital (Germany) and JAFCO Asia (Japan).

Silicon Sands Pty Ltd is an early spin-off company of Flinders University. The company is commercialising an energy-efficient method for producing silicon materials and polymers. The process reduces silicon production costs by chemically controlling intermediate colloidal nanostructures, resulting in high-yield synthesis of key silicon compounds.

The **Surface and Nanoscience Group** at the **University of Newcastle** aims to be a centre of excellence for the analysis and production of surfaces and interfaces. The Group has strong links with groups in France, Japan, Korea, the UK and the US. Its work with industry has centred on the application of surface analytical techniques to provide solutions to materials science problems such as corrosion, oxidation and increased wear.

Research is specifically focused on the use of surface analysis as a tool in solving materials science problems, understanding and optimisation of ultra-thin metal film deposition, growing and using polymer films, developing plastic solar cells and advanced surface coatings for composite materials, and using laser-based techniques for quantitative, sensitive surface analysis. Analytic instruments, such as the secondary ion mass spectrometry (SIMS), Auger electron spectroscopy/X-ray photoelectron spectroscopy (AES/XPS), scanning tunnelling microscopy (STM), near-field scanning optical microscope (NFSOM), electron microscopy (EM), allow the analysis and modification of surfaces from micron to nanometre scale.

TAG Technology is licensing a unique nanotechnology that when incorporated into coatings, textiles and films, allows these polymeric materials to block the flow of heat passing through them from one direction only. In doing so, it works to keep the temperature of any product coated with a thermally active granules (TAG®) coating or film as constant as possible regardless of shifts in the ambient temperature.

Although a number of materials can insulate or reflect heat, no other material has the ability to slow heat ingress from one direction only. TAG® can be formulated into a variety of coatings and products, and offers a wide range of benefits. For example, it has been shown that a paint containing TAG® lowers the internal temperature of a building by as much as 10–15°C in summer.

The TAG® technology also offers great potential to the power industry by improving generation efficiencies, reducing power losses through high voltage lines by 20–40 per cent and improving the performance of cooling towers. Other applications of TAG® technology include polypropylene films for foodstuffs, fire-fighting foams, window films and protective clothing. TAG Technology is currently selecting suitable partners to commercialise this technology internationally.

The **School of Material Science and Engineering** at the **University of New South Wales** has conducted extensive research in ex-situ nanocomposites of calcium phosphate and polymers in collaboration with the Mahatma Ghandi University, India. These projects included making nanoparticles, dispersing them in polymers and then using the tapping mode atomic force microscopy and focused ion beam studies of isotactic polystyrene/titanium dioxide composites; mechanical and thermal properties of poly (ethylene-co-vinyl acetate) calcium phosphate nanocomposites; and mechanical behaviour of polystyrene calcium phosphate nanocomposites. Researchers observed that by changing the concentration of poly ethylene oxide (PEO), the particle size of calcium phosphate could be almost linearly controlled.

The School also worked with ETH Zurich and the University of Technology, Sydney to evaluate the processing, structure and electrical properties of C/Co-polymer nanocomposites using polymethylmethacrylate (PMMA) and PEO by various methods such as solution, solution (mortar) and mechanical mixing. The project demonstrated that through mechanical mixing of the polymer powders, followed by compression molding, a very low percolation threshold of only 0.81 vol% C/Co could be obtained. This low threshold resulted from a segregated C/Co-network located at the polymer-polymer interfaces that was corroborated by SEM-micrographs and a theoretical model. In collaboration with the Materials Science Centre at the Indian Institute of Technology, Kharagpur, India, the School prepared and characterised polymer matrix nanocomposites using sustainable materials such as red-mud for electrical/magnetic application.

Pepfactants Pty Ltd develops and commercialises purpose-designed peptide surfactants with the novel ability to make and break emulsions and foams reversibly on demand. Known as Pepfactants®, other features of this class of peptides include their production by a sustainable means, biodegradability and

David Forder, CEO, of TAG Technology that is developing cooling nano-chemicals.

environmentally friendly material. The Pepfactants® technology has the potential to impact a variety of large and economically important markets ranging from healthcare and cosmetics to the petroleum industries. The company has exclusive commercialisation rights from **UniQuest Pty Ltd**, the main technology commercialisation company for The University of Queensland. The technology is the subject of an International Patent Application.The company is developing a number of proprietary products whilst actively engaging with the market to enter into collaborative partnerships to co-develop the Pepfactants® technology to meet the partner's specific needs.

The **Department of Physics and Advanced Materials** at the **University of Technology, Sydney** is researching nanocomposites and nanocoatings. The Department has prepared nanoparticle reinforced thermosetting resin matrix composites and has found that greater increases in strength and stiffness at low volume fractions can be achieved by using different particle sizes in conjunction with each other. It is also applying nano-thickness coatings to metals for increased wear and corrosion resistance. This process is low temperature and thus phase changes in the metal substrate are not induced. The Department has the capability to apply these coatings, test the interfacial strength and toughness, make the nanocomposites and perform mechanical testing.

The **Nanoscale Organisation and Dynamics Group** at the **University of Western Sydney** has conducted research on the development of light-weight, polymer-based composites, via the nanoscale dispersion of a number of reinforcing materials such as clays and CNTs in organic polymers. Its current research programs involve the electrically active composites that could be used in the next generation of solid-state batteries for the automotive industry and the super- tough composites to replace the conventional copper/chrome-based coatings used in the high-quality printing industry. These fundamental activities involve exploring modern technologies including synchrotron radiation facility to examine the interfacial interactions and differential scanning calorimeter/thermogravimetric analyser (DSC/TGA) thermal analytical facility to optimise the dispersion which leads to improved composite performance.

The Group is also working to design efficient stationary phases using computer modelling (ab-initio quantum mechanics, molecular dynamics and Monte Carlo) in conjunction with classical chromatographic analysis and state-of-the-art nuclear magnetic resonance (NMR) imaging to optimise molecular surface-solute interactions.

The **Very Small Particle Company Pty Ltd (VSPC)** manufactures nanoscale, complex metal oxides with optimised architectures and nanoscale features using its patented processing technology. These materials can be used in industries as diverse as vehicle exhaust catalysts, solid oxide fuel cells, gas separation membranes, batteries, industrial catalysts, opto-electronics, sensors, solar, pigments, structural ceramics and magnetics. The nanoscale characteristics of the materials typically enhance their properties, resulting in products that outperform coarser versions of the same materials.

VSPC's plant can produce approximately 60 tonnes of material per year. The plant is computer controlled and can easily scale up. The company is putting strategies in place for product and market development in areas with potential for very rapid commercial expansion and preferably with a significant environmental content. VSPC welcomes opportunities for collaborations that will accelerate its product and market development as well as its commercial outcomes.

XeroCoat Pty Ltd was formed to manage and commercialise a new low-cost coating technology developed by the University of Queensland. The coating provides anti-reflection and anti-fogging properties to surfaces such as glass and plastics. It is based on thin films of nanoporous silica, a layer of glass full of tiny invisible bubbles. XeroCoat coatings can be permanently applied to many surfaces and current research is developing the technology for products such as solar energy devices, consumer electronics, spectacles, sunglasses, sporting goggles, windscreens and bathroom mirrors. XeroCoat is working with the University of Queensland to provide even more functionality from this simple, low-cost coating.

Nano-Biotechnology and Medical Devices

Australia has a history of successes in biological and molecular sciences, positioning the country to make an impact in nanoscale biotechnologies.

Australian organisations are engaged in world-leading research into carbohydrate and protein chemistry for the development of new therapeutic treatments; advanced drug delivery systems using nanoscale particles; and the creation of biocompatible nano-engineered polymers for implants. Work in nanoscale bio-sensing is moving rapidly toward commercial success.

Australia has a well-deserved reputation for clinical research and the development and discovery of therapeutic agents. It is also taking a leading role in the development of many new fields of nano-biotechnology, including the creation of novel materials and devices for medical and diagnostic needs.

Australian Institute for Bioengineering and Nanotechnology (AIBN) building at the University of Queensland. Photo courtesy of the AIBN.

AorTech Biomaterials Pty Ltd manufactures highly biostable and biocompatible polymeric materials for use in the medical device, pharmaceutical and biotechnology industries. While AorTech Biomaterial's parent company, AorTech International plc, is listed on the London Stock Exchange's AIM share market, all research and development takes place in Australia. AorTech Biomaterials owns all the intellectual property for Elast-Eon™, a novel biocompatible polymer. Elast-Eon™ is used for cardiovascular, interventional cardiology, cardiac rhythm management (CRM), soft-tissue replacement, vascular and orthopaedic applications. Elast-Eon™ is a polyurethane-silicone co-polymer exhibiting the tensile strength, abrasion resistance and standard processability of a polyurethane and the haemo-compatibility, bio-compatibility and bio-stability of a silicone. Its enhanced bio-compatibility is due to the polymer's high silicone content.

Recently, the first FDA-approved human-use Elast-Eon™ was announced in collaboration with St. Jude Medical (SJM), a medical device manufacturer, and the material is now implanted as the insulating material for one of SJM's CRM devices. AorTech has several research projects in the pipeline, including an Elast-Eon™ Breast Implant and drug-eluting stents. AorTech works with commercial partners, tailoring formulations to the specifications of medical device manufacturers or developing new materials, processes and prototypes for use in specific applications, such as heart valves and spinal implants. In the past year, AorTech has entered into collaborations with several US-based medical device companies, including Allium Medical, Inc., Avalon Laboratories, Harland Medical and St. Jude Medical.

Astute Nanotechnology is the commercialisation company for the **Australian Research Council (ARC) Centre of Excellence for Functional Nanomaterials**. Research groups from the Australian National University, the University of New South Wales, the University of Western Sydney and the University of Queensland comprise the Centre of Excellence. Astute Nanotechnology was formed when the four universities agreed to commercialise the Centre's intellectual property by forming the company in a strategic relationship with **UniQuest Pty Ltd**, the main commercialisation company of the University of Queensland.

Astute Nanotechnology and the ARC Centre of Excellence for Functional Nanomaterials have identified clean energy, the environment and healthcare industries as areas in which nanostructured materials will have significant early impacts. The healthcare focus is drug delivery, biomaterials for orthopaedic and cardiovascular applications, and tissue repair.

Research at the **Australian Institute for Bioengineering and Nanotechnology (AIBN)** is at the intersection of biological, chemical and physical sciences. AIBN's internationally acknowledged research group leaders focus on nanotechnology-based imaging and drug delivery for therapeutic products, regenerative medicine (biology, stem cells and novel scaffolds), novel protein expression using metabolomics and systems biotechnology, and nanotechnology for energy and environmental applications.

These areas of research excellence are deployed on industry problems through consulting, partnering or contract research. AIBN's resources and skills link nanotechnology to the biological interface. Examples include nanoparticles developed to detect early cancer markers, 'smart surfaces' that mimic conditions in the body and encourage high rates of stem cell production, and engineering cells to produce the building blocks for plastics. AIBN has extensive links with industry, including DuPont, Intel and Merck, as well as collaborations with renowned institutions such as the Fred Hutchinson Cancer Research Institute, Massachusetts Institute of Technology and the Argonne National Laboratories. AIBN has more than 30 active collaborative arrangements in the US.

As a generator of new technologies and innovations, AIBN is committed to ensuring that promising technologies are commercially developed. This philosophy is integral to AIBN's translational research environment. To this end, AIBN interacts and collaborates with over 20 companies. It also has an intellectual property portfolio that currently consists of 15 patent families and close to 50 early-stage discoveries, and a culture of licensing and spin-off companies based on its high-quality research.

Research undertaken by the **Research School of Chemistry** at the **Australian National University** involves developing methods and strategies to measure, interpret and analyse diffuse X-ray scattering. These methods are applied to develop models for the crystal structures of pharmaceutical molecules. Diffuse X-ray scattering is used to analyse how the flexibility of certain classes of organic molecules influences their ability to form well-ordered crystal structures. Diffuse scattering gives information about how neighbouring molecules interact with each other – information not available from conventional crystallography. Such information may provide the key to why some compounds are difficult to crystallise while others have a tendency to produce different polymorphic forms. As molecules crystallise in more than one form, they may cause unexpected reactions in the body. The research project seeks to understand why materials form different polymorphs and to develop different processes to control polymorph formation.

The **Australian Nuclear Science and Technology Organisation (ANSTO)** supports the development of medical devices by providing technical support and process development to Australian companies, in particular to organisations in the field of orthopaedics and implantable devices. ANSTO characterisation tools are being used to study the structure and function properties at nanoscale level.

The **Australian Research Council Centre of Excellence for Electromaterials Science (ACES)** is a recognised centre of excellence in nanobionics research and commercialisation, with four research partners: the University of Wollongong, Monash University, the Bionic Ear Institute and St. Vincent's Health Melbourne. The Bionics Program within the Centre is investigating ways to improve the performance of the cochlear implant device by optimising the electrical interface with the central nervous system. Researchers are exploring new nano-structured inherently conducting polymers and carbon nanotube electromaterials and composites to assist in nerve regeneration, wound healing and bone regrowth. The Centre is developing electrodes that will deliver trophic, inhibitory or chemotactic factors and techniques for electrical stimuli to control cell adhesion and proliferation. These functions will be achieved by modifying the chemistry of electroactive conducting polymers and/or carbon nanotube composites to interface with and integrate into the body. The chemical and mechanical properties of the materials are being tailored for targeted applications, such as a new generation of cochlear implants, spinal cord and nerve repair, and then used in the development of novel wearable or implantable devices.

The research programs of the **Australian Research Council Centre of Excellence for Functional Nanomaterials** focus on the novel synthesis, characterisation and application of functional nanomaterials such as nanoparticles, nanotubes, thin films and nanoporous and nanocomposite materials. These materials are constructed by self-assembly at the nanometre scale (1–100 nm)

Point of Care Pathogen Diagnostic Kit incorporating micro and nano technologies. Image courtesy of Catapult Innovations.

and possess improved properties to make ideal materials for adsorbents, catalysts, sensors, fuel cells and battery systems. They are also attractive for biotechnology applications due to the controlled effectiveness of protein material, cell material and tissue material interactions.

The Centre is specifically interested in the following: clean energy production and use (gas to liquid conversion, hydrogen production and storage, fuel cells, and high energy density batteries); environment technologies (photocatalytic reduction of pollutants in water and air, economic removal and recovery of organic vapours, greenhouse reduction and use); and healthcare (biomaterials for orthopaedic and cardiovascular applications and tissue repair).

Partners include the University of Queensland, University of New South Wales, the Australian National University and the University of Western Sydney. The Center's aim is to create platform technologies for products in the fields of bioengineering and nanotechnology, with a strong focus on bringing products to market through its commercialisation arm, **Astute Nanotechnology**. Some international collaborators include: Carbon Nanotube Centre, Chinese Academy of Sciences, China; Forschungszentrum Julich, Germany; The Nanopartices Lab, Swiss Institute of Technology, Switzerland; Centre for Nanoscience and Nanotechnology, Georgia Tech, US; University of California at Santa Barbara, US; Particle Engineering Research Center at the University of Florida, US; and the University of Washington, St Louis, US.

Bio21 Molecular Science and Biotechnology Institute (Bio21 Institute) is located at the **University of Melbourne** and is the core physical development within the Bio21 Cluster Project. The Institute is a multidisciplinary research centre that specialises in biomedical and environmental biotechnology. It is conducting research into biocompatible materials for medical implants, nanoparticle-based therapeutics, and medical and environmental biosensor devices. Its nanobiotechnology programs are linked strategically with the university's recently established Centre for Nano Science and Technology, as well as the Australian Synchrotron.

The recent establishment of the Institute's **Nanotechnology and Microscopy Centre** has been a key enabler of its research program. The facility incorporates high-resolution electron microscopy for imaging, microanalysis and nanofabrication; an associated clean room; and state-of-the-art instruments for imaging the molecular structures of large protein complexes and the distribution of functional components within cells by cryo-electron microscopy. The Institute is concentrating on the development of nano thin-film-based drug delivery capsules, biocompatible tissue regeneration scaffolds, protein chip arrays for high throughput screening of candidate drugs, biosensors for use in pre-clinical development and environmental monitoring, phosphopeptide-based nanomineral delivery systems for tooth repair, light-emitting polymers and DNA-based nanovoltaic systems.

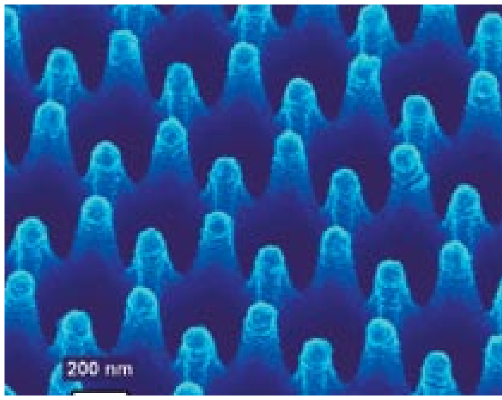
BioChip Innovations (BCI), in association with its strategic partner in Singapore, is developing fully electronic silicon microarray biochip platforms that integrate nucleic acid extraction and amplification with an advanced nanotechnology detection system. These nano-biochips will be pre-optimised for RNA and DNA testing and will greatly simplify gene probe assays and amplification procedures such as polymerase chain reaction used in research and diagnostics. The company is applying these biochips to develop fast, extremely sensitive and highly multiplexed diagnostic products. BCI anticipates bringing its first nano-biochip to market as a research-use device early in 2008. BCI's first diagnostic product using nano-biochips will diagnose the influenza type A virus by detecting and identifying any of the 144 known sub-types of the virus (one of which is H5N1 – avian flu), detect mutations that induce resistance to the drugs Tamiflu and Relenza, and detect mutations that enhance pathogenicity. The pre-optimised nano-biochips will enable BCI to rapidly develop new products for all sectors of the RNA and DNA diagnostics market including medical, veterinary, forensic, agriculture, food and environmental applications.

Bio-Layer Pty Ltd is a materials science company that has developed a High Throughput Surface Discovery (HTSD) platform for the rapid design of novel materials for the biotechnology, diagnostics and pharmaceutical industries. The combination of rational design, combinatorial chemistry and nanoscale surface science has resulted in the creation of a process to develop and test thousands of surface coatings simultaneously for a given application. Coatings generated from the HTSD platform are then applied to industry-standard substrates, such as plastic and glass. Bio-Layer's initial focus is providing materials solutions that change the way immunoassays are developed for the diagnostic industries. The HTSD platform has enabled the development and testing of numerous surface coatings. These were applied to various substrates and screened to identify the optimal composition for a particular type of diagnostic test surface. A new line of products resulted from the HTSD called Mix&Go™. For all immunoassays tested, Bio-Layer's technology achieved three key goals: a significant improvement in sensitivity (three- to 70-fold); increased stability and product shelf life; and lower manufacturing costs. These characteristics are highly desired by manufacturers of diagnostic kits and immunoassays. Bio-Layer's Mix&Go™ products have already been incorporated into commercial diagnostic assays used in research and distributed by a major life science company.

BioPharmica Ltd manages a strong portfolio of biomedical technologies emerging from research by leading universities, medical institutes and hospitals across Australia. The company provides product development and commercial guidance, while the institutional partner provides the majority of the infrastructure and research expertise. In conjunction with Swinburne University, BioPharmica is in the process of commercialising the Surface Enhanced Raman Spectroscopy (SERS) nanoprobe, a component being developed to enable the microscopic tip of an optical fibre to be used in biosensors. The SERS nanoprobe is being developed for nanotechnology applications from military and water monitoring applications to medical environments.

BioSenZ Pty Ltd created and patented BioSAW technology for chemical and biological sensing and microfluidic delivery of samples to BioSAW chips in field-portable electronic read detectors with sensitivities at the parts-per-billion level. The technology builds a BioSAW using a Love-mode surface acoustic wave device as an extremely sensitive mass balance. A selective coating is applied to the BioSAW device which is then exposed to the environment (either air or liquid). Substances of interest attach to the selective surface and the BioSAW detects the change in the attached mass as a change in frequency. Selective coatings currently exist for toxic industrial gases (H_2, CO, NO_2), micro-organisms (LPsg1 Legionella, Salmonella and E.coli), and some organic molecules (pesticide residues). The BioSAW technology can also be adapted for other precision mass balance applications in nanotechnology. BioSenZ is seeking direct investment to further develop its technology.

The **Browitt Nanoparticle Laboratory** at the **Australian National University** has developed a medical diagnostic technology known as FibrinLite. FibrinLite is a radio-labelled nanoparticle that has potential broad clinical applications in the diagnosis of deep vein thrombosis and a variety of diseases that present fibrin deposition, such as some carcinomas. FibrinLite is a nanoparticle



The novel nanostructure optical fibre technology called honeycomb optical fibre (HOF), pictured above, represents a breakthrough in the area of SERS. Image courtesy of BioPharmica Ltd composed of a central core of a suitable radioisotope, encapsulated within layers of graphite. The nanoparticles are produced by a bench-top machine using a modified Technegas® process. The graphite provides excellent chemical protection for the isotope from the body's internal environment and, irrespective of the isotope encapsulated, the body reacts to the chemical identity of the graphite in the same way. Therefore, a host of different diagnostic and therapeutic isotopes can be produced by this process.

The **Cell and Nanobiotechnology Research Group** at the **University of Technology, Sydney (UTS)** is researching artificial cell membranes to improve the bio-compatibility of implanted tissue and cells, and implant functionality by bypassing the body's immune system. The membranes also provide novel platforms for advanced nanosensors. The development of nanobiosensors is based on mesoporous gold electrodes for the measurement of electrochemical double layer capacitance. Mesoporous gold electrodes have near ideal capacitor behaviour under potential-sweep and potential-step conditions.

The Group is also conducting research on targeted drug delivery and gene therapy. It has formed alliances with international pharmaceutical companies on drug discovery and adaptation projects, and with diagnostic companies for healthcare applications.

Australia nanobiotechnology companies have an international network through participation in the European Union's EC Network of Excellence in Nanobiotechnology (Nano2Life). In Australia, OzNano2Life is coordinated by UTS to represent key Australian scientists and research institutions. The current joint international research program has six Australian based projects: the 'artificial cell', G-protein coupled receptor sensor technology, immobilisation of proteins and novel biochip array platforms, biomimetic nanosprings and novel nanostructured elastomeric materials, nanomechanics of lipid membranes using holographic interferometry and nanoscaled biological screening devices in microfluidic applications. OzNano2Life is now building from the current research program into the next phase of developing nanobiotechnology capabilities.

The **Centre for Advanced Macromolecular Design (CAMD)** at the **University of New South Wales** is dedicated to the synthesis of complex polymer architectures for the development of self-assembled structures on the nanoscale. These structures range from core-shell particles for drug delivery, to self-assembled films with a highly regular array of pores. The self-assembly process is based on the design of well-defined polymer structures.

The investigation of fundamental aspects of the polymer synthesis, including a detailed polymer analysis using the latest analytical tools (high resolution MS), is a prerequisite for successful self-assembly and is therefore the Centre's research focus. Depending on the application, functional structures such as carbohydrates, peptides, liquid crystalline or conductive sequences are incorporated into the polymer and its properties tailored towards the application.

CAMD has strong collaborations with industry, hospitals and other research centres to optimise the performance output of polymeric nanomaterial used in medical, biomedical, membrane or photonic science. A strong focus is on the synthesis of core-shell nanoparticles for the improved delivery of anti-cancer drugs. These core-shell particles enable a temporal control of drug release and prevent fast clearance of the drug carrier from the body resulting in reduced drug administration for the patient.

The Centre is also working on the development of next-generation drug carriers that can control the drug concentration within the body and influence the distribution of the nanoparticle within the body, hence, delivering the drugs only to those sites within the body where they are needed.

The **Centre for Biomedical Engineering (CBME)** at the **University of Adelaide** is investigating T-ray techniques to potentially provide a fast, non-invasive way to detect and diagnose skin cancer by imaging the target area at different depths below the skin surface. While there is proof of concept that T-rays can distinguish between cancerous and normal tissue, the mechanisms underlying this differentiation are not well understood. The Centre is conducting research to determine whether T-rays can be used to discriminate malignant and benign skin disease or different skin cancer types. This study will establish whether T-ray spectroscopy can detect skin cancers and differentiate between tumours at various stages of tumourgenesis.

Researchers are also investigating the use of T-ray spectroscopy to probe the conformation of biomolecules. The elucidation of fundamental mechanisms of T-ray interaction with biomolecules will lead to improved methods of biomolecuar fingerprinting. This will enable investigation of processing of biomolecular self-assembly and the classification of viral biothreats, which has applications in defence, security and pharmaceutical processing.

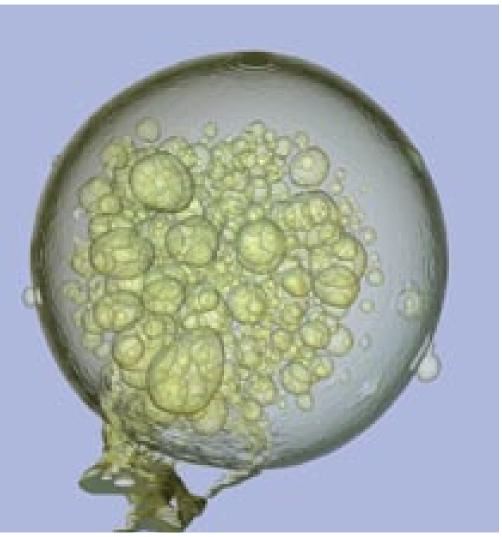
The **Centre for Green Chemistry** is located at **Monash University.** It uses custom-built research laboratories with state-of-the-art facilities. The Centre's research involves advanced enabling expertise and intellectual property in cleaner synthesis technology and green biotechnology. Current research projects include the creation of nanoscale separation devices; chemical arrays for mass screening and research including chemical detection for environmental and bio applications; and nano dimensional polymeric materials containing structurally defined cavities for use in chemical and biological sensor devices and synthesis. It is also investigating the application of the metrics of green chemistry in the nanosciences and the use of assaying materials to solve environmental problems, including the molecular design aspects of the toxicology of nanoparticles.

The Centre for Green Chemistry is collaborating with the University of Liverpool, UK, the Swinburne University of Technology, numerous other universities in Australia and overseas, and several CSIRO (Commonwealth Scientific and Industrial Research Organisation) Flagship Clusters.

The **Centre for Lasers and Applications (CLA)** at **Macquarie University** pursues the creation of biophotonic applications including the advanced sensing and imaging techniques using fluorescence, two-photon excitation, coherent Raman scattering and confocal microscopy. Other applications in this field include innovative, cost-effective forms of flow cytometry of pathogens (such as Giardia in drinking water), and development of novel high-power multi-wavelength lasers for dermatological treatment.

The CLA's **Nanobiophotonics Research Group** focuses on ultrasensitive detection of trace analytes. The need for ultrasensitive and specific biomedical diagnostics requires the development of optical and photonic detection/sensing technologies capable of detection and analysis down to a level of single biomolecules. The significance of such technologies is growing in areas such as medicine, environmental protection and biosecurity.

Dr Chris Elvin from CSIRO. Image courtesy of CSIRO



3D tomographic reconstruction showing the internal structure of a CeramiSphere™. Data acquired using XRT Limited's X-ray ultraMicroscope (XuM) technology by Dr Sherry Mayo, CSIRO Manufacturing and Infrastructure Technology. Sample courtesy of CeramiSphere Pty Ltd.

Nanobiophotonics offers tools to meet the technical challenges of rapidly and specifically detecting various chemical and biological agents at trace concentration levels. The techniques used include various spectroscopies such as fluorescence, Raman scattering, sensitivity-enhancement by surface plasmon resonance detection of biomolecules and rapidly swept cavity ringdown spectroscopy for trace-level diagnostic monitoring of gas-phase molecules in human breath (for example for clinical tests in hospitals).

The **Centre for Nanoscience and Nanotechnology (CNST)** at the **University of Melbourne** fosters convergence in science and engineering to develop applications for biosciences, biotechnology and nanoparticle-based medicines and medical diagnostics. The Centre's flagship projects are quantum computing and nanoelectronics, quantum dot nanocomputing, tissue engineering, particle-based drug delivery and bio-labelling, and nanoengineered particle-modified surfaces.

The **Centre for Nanotechnology and Biomaterials** is a multidisciplinary research facility at the Australian Institute for Bioengineering and Nanotechnology (AIBN), located at the **University of Queensland**. The Centre works in partnership with three prominent US-based institutes: the Fred Hutchinson Cancer Research Center, the Seattle Biomedical Research Institute and the University of Washington. It focuses on creating novel materials and devices for medical and diagnostic needs.

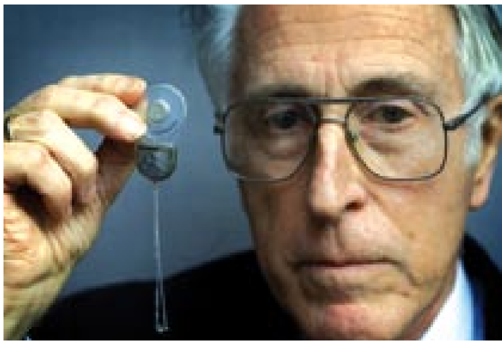
The Centre is pursuing a number of genetic screening and drug discovery applications using colloidal particles that are uniquely optically 'barcoded'. The platform colloidal systems are currently being applied in a number of areas including early detection of infectious diseases and cancers.

The Centre's Biomarker Project focuses on cervical and breast cancer detection using recently discovered genetic cancer biomarkers. It is also researching the development of biosensors for the detection of infectious diseases such as malaria, pulmonary tuberculosis, tuberculosis meningitis and trypanosomiasis.

Other research includes rapid protease detection of enzymatic cleavage sites for the development of peptide drug leads for Dengue Fever and West Nile viruses. The Centre also pursues artificial matrices for human tissue and bone replacement.

CeramiSphere Pty Ltd is commercialising sol-gel encapsulation technology developed at the Australian Nuclear Science and Technology Organisation (ANSTO). CeramiSphere's patented technology encapsulates active molecules in ceramic particles for controlled release applications with release rates that can be tailored to the application. CeramiSphere's technology has a particular focus on advanced drug delivery, surface protection (biocides, anti-corrosion) and cosmeceuticals. Other potential applications include veterinary care, agrichemicals, functional foods and household care products. Key features of CeramiSphere's technology are that the encapsulation process is conducted at ambient temperatures and release rates can be varied independently of particle size. The use of ceramics, such as SiO_2, rather than polymeric and organic substances, makes the technology more stable and bio-friendly than existing controlled-release technologies. In addition, the ceramic nature of the particles makes them mechanically and chemically resistant. CeramiSphere is seeking partners to develop commercial products and investors to fund future activities.

Cochlear Ltd's bionic ear implant technology electronically stimulates the auditory nerve to provide safe, reliable and effective treatment for moderate to profound sensorineural hearing loss. Surgical use of the implant in Australia commenced in 1982 and it was the first implant of its kind to gain US Food and Drug Administration approval for use. An electrode array is implanted into the patient's cochlea, with platinum electrodes attached to a receiver/stimulator under the skin above the ear. The receiver/stimulator receives radiofrequency signals from an external attachment. A fundamental aspect of the technology is the nanoscale bio-material interface between the metal electrode implanted in the cochlea and the nerve endings they stimulate. The electrode array includes 22 small platinum electrodes over a 17 mm length and is only 0.6 mm wide, tapering to 0.4 mm at its very tip. Cochlear has secured around 70 per cent of the world market in hearing implants.



Inventor of the Nucleus Cochlear Implant, Professor Graeme Clark, during a press conference holding one of the Australian made devices.

The **Cooperative Research Centre for Environmental Biotechnology (EBCRC)** develops advanced biotechnologies based on biological systems to improve the management of waste materials and by-products, provide biotechnology-based solutions to industry issues, and to recycle waste into useful products. EBCRC concentrates its research and commercial efforts in three core areas: biofilm prevention and dispersal, rapid in-field microbial detection and control, and bioprocesses such as bioremediation and industrial waste-water treatment. This research is applied to processes in the environmental, agricultural, veterinary, mining and medical industries. The EBCRC Rapid Pathogen Detection Strategies for the Environment project is developing robust and accurate systems to rapidly detect the presence of microbial contamination in real time. These systems will use a combination of sophisticated gene technology and nanotechnology to design sensors that can quickly detect the presence of problem organisms in water or food. This technology is based on detection of DNA using a variety of techniques including PCR, nanobeads and microchip technologies for field use.

The **Cooperative Research Centre for Oral Health Science (CRC-OHS)** brings together Australian expertise in oral health research, domestic manufacturing capability and global market experience. CRC-OHS is an unincorporated joint venture between the University of Melbourne, CSL Ltd, GC Corporation, Recaldent Pty Ltd and Monash University. Though the industry parties pursue different commercial fields, they have common interests in terms of technology. One specific area of research concerns tooth remineralisation. Recaldent® is a marketed anti-caries product that remineralises demineralised tooth enamel. This is being developed by CRC-OHS and consists of peptides derived from milk proteins called caseins (known as casein phosphopeptides) complexed with calcium phosphate. The casein phosphopeptides stabilise nanometer diameter particles of amorphous calcium phosphate and provide a source of bio-available calcium and phosphate ions under the conditions of pH and temperature found in the oral cavity. The nanocomplexes have been shown to replace the calcium and phosphate in demineralised enamel, thereby strengthening teeth. As Recaldent® is an anti-cariogenic agent, it can be incorporated into toothpaste, mouthwashes and chewing gum. CRC-OHS is currently studying the structural and functional relationships and mechanisms of these peptide-mineral complexes and their interaction with salivary proteins on the tooth surface.

The **Cooperative Research Centre for Polymers** is developing specialty polymers for a wide range of applications in the biotechnology, manufacturing, mining, agricultural and energy sectors of the economy. It conducts research in four key areas: biomedical polymers, advanced polymeric materials, polymers for sustainable development, and engineering and design. Participants in the CRC include 10 universities, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australian Nuclear Science and Technology Organisation (ANSTO), 10 companies, the Australian Stem Cell Centre and the state of Victoria.

The Centre is developing nanotechnology in many of its research projects. It is developing 'smart' polymer surfaces that contain biological information to control cell function and fate for use in biomanufacturing applications. The Centre is also developing biopolymer nanoparticles for single injection vaccine delivery.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) has developed many nanostructured materials for biomedical applications. These include biodegradable polymers for tissue engineering and polymers for ophthalmic applications, bioactive coatings for use in medical diagnostics, biosensors for controlling cellular response, thin film materials and surfaces including metals, nitrides, carbides, oxides, alloys, diamond-like carbon, hydroxyapatite and super-hard nanocomposites. CSIRO is also using a variety of textile fabrication methods, including electrospinning, to develop nanofibrous, biocompatible, biodegradable textile implants as nerve repair guides and scaffolds for the tissue engineering of non-load-bearing tissues.

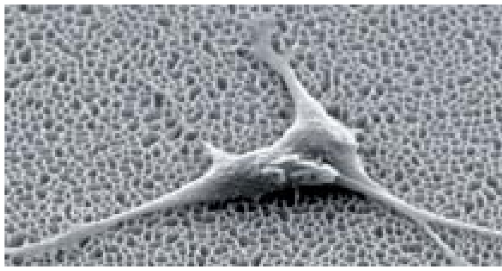
CSIRO draws on expertise in protein engineering and nanomaterials science to develop new platforms for disease diagnosis using advanced medical imaging technologies. One approach is the development of bioconjugated nanoparticle contrast agents for use in MRI imaging. **EvoGenix Pty Ltd** and **Avipep Pty Ltd** are examples of spin-off companies based on CSIRO research in protein engineering. Mayne Pharma, meanwhile, is currently commercialising novel self-assembling drug-delivery systems based on CSIRO nanomaterials science.

In the bioremediation area, CSIRO has developed and patented nanostructured mesoporous materials for the specific separation and remediation of heavy metals and pathogens, while bio-functionalised self-assembly structures that specifically absorb and inactivate biological toxins are also under investigation.

CSIRO is seeking industry and venture partners to progress its biopolymer technology for medical applications. CSIRO has previously been successful in developing other materials technologies for the medical industry, including the formation of **PolyNovo Biomaterials Pty Ltd**, **Aortech's** Elast-Eon™ and the CIBA Vision Night & Day™ and O2OPTIX™ contact lenses.

The new biopolymer technology includes a process to produce recombinant resilin proteins and rapidly cross-link them into highly elastomeric biomaterials. **Resilin** is the elastic protein that enables insects to perform their extraordinary jumping feats. The inventors at CSIRO are focused on developing novel, biocompatible materials such as resilin for use in medical applications. CSIRO's novel technology can be applied in the preparation and use of biocompatible materials, with broad medical applications in reconstructive surgery, tissue engineering and coatings. The process satisfies a significant need for new materials in the biomedical industry to replace existing biopolymers and rubbers which generally lack the full range of properties desired.

The technology is based on a facile photochemical method that rapidly cross-links recombinant resilin solutions in the body into insoluble materials, effectively turning a liquid into a solid in a matter of seconds. The physical and biological characteristics of the cross-linked biopolymers produced using the technology can be tailored to specific clinical needs. Resilin has demonstrated a resilience of 98 per cent, which is a measure of its ability to snap back into shape after being deformed. This is considerably greater than rubber products, making it particularly useful in areas where there is repetitive motion, such as in the spine. Resilin can be applied using equipment that is already in common use among surgeons, so no changes in surgical procedures are required. To date the technology has been tested in several animal trials and has shown biocompatibility and excellent performance against industry standards. There is commercial interest in resilin from several biomedical companies.



Neuronal cells growing on porous silicon. Image courtesy of Flinders University.

Research at the **Flinders University BioNanotechnology Laboratory** focuses on the development of new nanostructured materials with superior properties for applications such as biosensors, biochips, biomaterials and drug delivery. Most applications for these new types of materials are in the biomedical area, where the basic target is the improvement of human health.

The Laboratory is developing interference-based optical transducers from porous silicon to detect biological material. These biosensors are highly sensitive to and will allow the throughput detection of disease markers, genetic information, environmental toxins and drugs. The Laboratory is currently taking biochips to the next level by printing real cells instead of DNA or proteins using robotic microarray printers. The Laboratory uses its surface chemistry techniques on these biochips to control where cells grow. In a related program, it is developing coatings with switchable, stimuli-responsive properties to better control how proteins or cells attach to surfaces.

The Laboratory's unique approach to the compatibility of materials to cells and tissues allows it to investigate the effects of both surface topography and surface chemistry of silicon-based materials on cell and tissue growth. This is important for tissue engineering and the development of advanced biomaterials.

The Laboratory can generate nanostructured synthetic materials such as porous silicon and porous alumina by using electrochemical etching procedures. In addition, the Laboratory has access to natural nanostructured biominerals such as the silica scaffolds of diatoms. Thin films and coatings are made in the laboratory by a variety of methods, including plasma processing, chemical vapour deposition or electropolymerisation. Patterns are generated by laser ablation, microcontact printing and photolithography.

The Laboratory has expertise in generating these materials and coatings, in their characterisation as well as subsequent organic chemistry on the surfaces. The latter provides functionalities for attachment of biopolymers such as DNA and proteins. This step requires skills in surface chemistry, both preparative and analytical, and synthetic organic chemistry. The Laboratory has infrastructure and equipment for sophisticated organic synthesis, material fabrication and surface modification. It also has sophisticated characterisation equipment, including an atomic force microscope and various optical spectroscopes, microscopes and scanners, microarray printers and an optical tweezer. It can perform molecular biological manipulations, solid phase peptide and DNA synthesis and cell culture.

The **Ian Wark Research Institute (The Wark™)** at the **University of South Australia** is the **Australian Research Council Special Research Centre for Particle and Material Interfaces**. It is also the headquarters of the Australian Mineral Science Research Institute (AMSRI), a virtual institute embracing outstanding research teams at University of South Australia, the University of Melbourne, the University of Newcastle and the University of Queensland. The Wark™ conducts a blend of fundamental and applied research across a broad range of industry sectors and research areas including: minerals processing; interparticle forces and adhesion; wetting and particle adsorption; nanotechnology and nanolubrication; biotechnology; bio and polymer interfaces; biomedical and biodental implants; pharmaceutical; metals; ceramics; composite materials; surface modification and coatings; surface engineering; molecular modelling; computational colloids; food; pigments; and the environment, including mine site remediation.

With internationally competitive research strengths, The Wark™ works with overseas researchers to develop new products from nano and biomaterials. It has world-leading research capability in nano and biomaterials, and a proven ability to disseminate research outcomes to Australian industry and the community for commercial and strategic benefit. The research program is supported by postdoctoral staff from Germany, India and Canada. It is supported by six Australian companies, Monash and Sydney Universities and nine European laboratories: University of Bristol, UK; Abo Akademi, Finland; Swiss Federal Institute of Technology, Switzerland; Saarland University of Technology, Switzerland; Lulea University of Technology, Sweden; University of Ulm, Germany; Max Planck Institute for Colloids and Interfaces, Germany; and the Royal Institute of Technology, Sweden.

Ongoing programs at The Wark™ are concerned with nanoparticles, liposomes, dendrimers, micelles, emulsions and porous materials as delivery vehicles. A particular focus is to gain further understanding of how nanostructured materials and self-assembled particulate systems can be engineered for optimum use as delivery systems or carriers for a wide range of therapeutic molecules, for example poorly soluble drugs, peptides and proteins. One of The Wark's contractual research projects is with pSiMedica Limited in the UK on peptide and protein delivery from the company's BioSilicon™ porous drug delivery vehicle. Another project involves gaining information about the mechanism of dendrimer interaction with charged solid surfaces to understand the driving forces of dendrimer interfacial behaviour and its application to biologically relevant conditions. Current investigations are considering the interaction of dendrimers in conditions to mimic their in-vivo environment, particularly their interaction with plasma proteins, and with model lipid bi-layers using a range of techniques, including ATM, quartz crystal microbalance, surface Plasmon resonance spectroscopy and dynamic light scattering.

In collaboration with the Royal Adelaide Hospital and the Australian Nuclear Science and Technology Organisation (ANSTO), The Wark™ is targeting functional nanostructures to tumours through exploiting the ability of the nanoparticles to cross the abnormal fenestrated vasculature of a tumour, particularly with 'stealth' liposomes that contain doxorubicin. The ability to apply 'stealth' coating to nanoparticles, and avoid recognition by the defence proteins, has been achieved using PEG-copolymers. These polymers have been synthesised at The Wark™ and have been physically self-assembled onto porous silica nanoparticles at ANSTO. The copolymer was able to displace the surfactant Tergitol used during the synthesis of the particles. The dense PEG layer was able to completely screen the charges originating from the silica nanoparticles and to provide excellent colloidal stability in physiological conditions.

In collaboration with the Royal Adelaide Hospital and the Melanoma Centre of the Sydney Cancer Centre, The Wark™ develops functionalised superparamagnetic magnetite nanoparticles for immuno-targeting cancer cells. The project has three main topics: dextran coated nanoparticles for the diagnosis of metastases in lymph nodes; hybrid materials consisting of PEG-coated nanoparticles and antibodies for the targeted diagnosis of tumours; and hybrid materials consisting of nanoparticles with polyelectrolyte shells which are loaded with common cancer drugs for the targeted diagnosis and treatment of tumours.

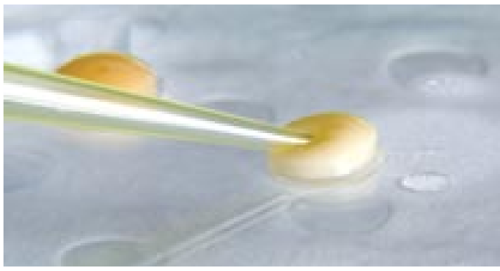
In conjunction with CSIRO, The Wark™ has cloned and expressed the first exon of the Drosophila melanogaster CG15920 gene to bio-synthesise a soluble protein called pro-resilin. This recombinant protein can be suitably cross-linked into a highly elastic biomaterial by rapid chemical or photochemical cross-linking. The protein-based elastomer obtained exhibits exceptionally high resilience characteristics (more than 90 per cent) and is insensitive to temperature over a wide range (5 to 80°C). The material's extraordinary resilience and durability indicate that it could have applications in spinal disc implants, components of vascular prostheses and perhaps as high-efficiency elastomers in micro-mechanical systems (MEMS).

iCeutica's nano-drug technology has the potential to solve two major problems facing the pharmaceutical industry by extending the life of existing drugs and improving the safety and efficiency of delivery. The company's encapsulated organic nanoparticle (EON™) platform can address the problem of the estimated US$60 billion worth of drugs coming off patent in the next decade and the solubility and other bioavailability hurdles of existing drugs. Nearly 40 per cent of new chemical entities are limited in their development by poor water solubility, while up to 20 per cent of approved drugs have sub-optimal performance in relation to solubility.

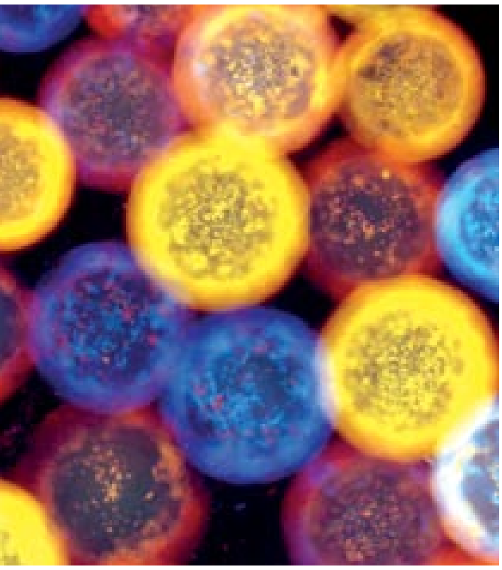
iCeutica's technology uses solid state chemistry to synthesise nano-sized drug particles in a controlled manner. The particles are synthesised into a carrier phase, which can optionally be removed to leave the dispersed nanodrug. This patented technology is environmentally friendly and solvent free. The EON™ platform produces nano-sized particles to enhance pharmaceutical drug performance by achieving clinically significant drug levels faster using lower doses. Nanodrugs produced with the EON™ platform offer wider flexibility in delivery, access to alternative delivery mechanisms and the potential to reduce side effects caused by dosage levels or toxic carriers.

The **Laboratory for Nanoscale Interfacial Design Group** at the **University of New South Wales** focuses on the functionalisation of surfaces for the development of novel biosensors and for biomaterials applications.

Using the bottom-up principle of nanofabrication, self-assembled monolayers are used to modify the electrodes and optical devices with biomolecules to provide selectivity for a target analyte. The Group is developing electrochemical, optical and nanoparticle biosensors to detect specific sequences of DNA, drugs and other small molecules in biomedical samples; to detect multiple metals in drinking water on a single chip; to monitor pesticides in environmental samples; and to provide warnings of bio-warfare agents. The Group is also undertaking activities relating to functionalised surfaces to understand the adhesive interaction of cells with manufactured surfaces and to produce surfaces that can monitor enzymatic activity.



Resilin in petrie dish. Image courtesy of CSIRO.



Nanomics platform technology – multi bead on bead. Image courtesy of Nanomics Biosystems Pty Ltd.

Melbourne Ventures is the technology transfer company for the **University of Melbourne**. The company has a number of nanotechnologies available for commercial development, including novel nanoporous polyelectrolyte polymer microspheres. Developed at the University's **Centre for Nanoscience and Nanotechnology (CNST)**, these microspheres have applications in controlled release drug delivery, biocatalysis and separations.

Core-crosslinked star polymers that form the basis of flexible honeycomb films and coatings with a wide range of functions are also ready for commercial development. The films can be deposited on non-flat or irregular surfaces and have applications in sensing, controlled release, biocatalysis and separations. These innovative, customisable materials are being developed in the University's **Department of Chemical and Biomolecular Engineering**.

MiniFAB creates advanced products through the implementation of unique scientific, engineering and manufacturing know-how. MiniFAB designs, integrates and manufactures polymer micro and nano-engineered systems for the biotech, health, agriculture and food industries. MiniFAB works with clients to develop product strategies, create manufacturing methods, provide pilot and batch scale manufacturing meeting regulatory compliance testing, and create volume manufacturing operations.

MiniFAB's approach to technology allows for simplified manufacture of products using batch processing, photolithographic techniques, and minimal types of materials and numbers of components. This approach leads to reduced manufacturing costs, increased product reliability and the development of low-cost disposable devices. MiniFAB uses high throughput manufacturing strategies, matched with rapid turnaround development tools, enabling the company to demonstrate solutions quickly.

MiniFAB's nanotechnology expertise lies in packaging nanotechnologies into applications, such as applying nanofilms to a micro-fluidic chip and then incorporating it into a complete system for applications such as diagnostics. MiniFAB has also implemented nano-imprint lithography for the fabrication of nanoscaled structures. The company has developed numerous devices and components, including micro-chemical reactors, biosensor cartridges, bio-fluidic handling systems and connectors, and integrated active components such as valves, pumps and optical elements.

A high-profile example of MiniFAB's nanotechnology work is its involvement in the SmartHEALTH Integrated Project (IST-NMP-2-016817), which is part of the European Union's Sixth Framework Programme and aims to develop the next generation intelligent medical diagnostic platforms. MiniFab is the only non-European member of this project and is developing a manufacturing packaging strategy for nanotechnology-based biosensors for biological species detection.

The **Monash Institute for Nanosciences** brings together a large array of nanoscience research and development expertise from across **Monash University**. This includes expertise covering medicine, pharmacy, chemistry, physics, engineering, mathematics, food sciences and materials. Researchers undertake basic and applied research at the nanoscale with a strong multi-disciplinary focus.

The Institute's application-driven research includes investigation into nanoscience-based technologies impacting on medicine in areas such as nano-biotechnology, nanotoxicology, biomaterials and bioengineering, chemical- and device-based drug delivery, microfluidics, disease diagnosis, medical imaging, and therapeutics and theranostics. It is currently undertaking projects on the development of: a pulmonary drug delivery system for inhaling therapeutic medicines through the nose and into the lungs, where it is fed directly to the blood; a transdermal drug delivery system for taking therapeutic medicines through the skin using a patch that provides controlled release; and nanomaterials for use in regenerative medicine.

The Institute also has a food and nutrition program investigating areas such as food production, storage and nutrient uptake, product formulation, processing technologies, quality control and sensor technologies. Current research includes the development of a food quality monitoring device that is able to detect pathogens in food and the development of food additives based on nanoscience that improve taste and physical attributes of foods and maintain food quality during transport and handling more effectively than current additives and methods.

The **Murdoch Applied Nanoscience Research Group** at **Murdoch University** has a cluster of ongoing applied nanoscience research projects. It has engineered a nanomembrane with pores ranging from 62 nm to 800 nm to investigate its effects on skin cell attachment and growth. In late 2006, its collaboration with the McComb Foundation was rewarded with a patent for the use of this nanomembrane for large skin bioengineering applications. It is also investigating the use of a nanopolymer for fast and sustained release of anti-stroke drugs for stroke victims. Another project will investigate the applications of nanohydroxyapatite (bone mineral) for biomedical uses.

Nanomics Biosystems Pty Ltd is a spin-off company formed to develop commercial applications for the **Centre for Nanotechnology and Biomaterials** at the University of Queensland. The company's unique technologies – OptoPlex™ and colloidal carrier-reporter barcoding – consist of optically barcoded ceramic nanoparticles on which oligonucleotide or peptide biomolecules can be either attached as fully intact moieties (for small multiplexed libraries) or synthesised in situ via combinatorial chemistry (for extremely large libraries).

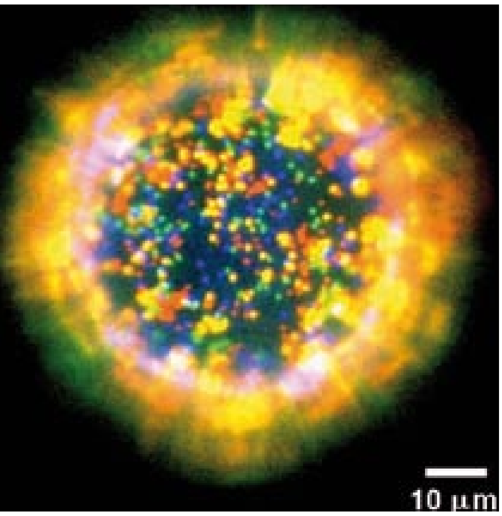
Nanomics Biosystems' platform technologies can be tailored for essentially any discovery, screening or diagnostic application, and the nanoparticles can be detected using any flow cytometer. The company is focusing on developing these technologies for the early diagnosis of cancer and infectious disease, and for the discovery of new biomarkers. It is also exploring additional opportunities in biomedical research and diagnostics.

The company was awarded a three-year biosecurity project in collaboration with the **Australian Biosecurity Cooperative Research Centre (CRC) for Emerging Infectious Diseases** and the **CRC for National Plant Biosecurity**. The Biosecurity Project seeks to develop new tests to detect pathogens that are highly significant biosecurity threats to public health and agriculture, including influenza (such as the highly pathogenic avian influenza, or bird flu), foot and mouth disease, arboviruses of public health and livestock significance, and plant pathogens.

The **Nanoscale Organisation and Dynamics Group** is a multidisciplinary research team at the **University of Western Sydney (UWS)**. Its goal is to establish UWS as an internationally recognised research centre for molecular association, organisation and dynamics with an emphasis on nanobiotechnical applications (for example drug binding and nanofluidics).

The Group has diverse research capabilities that range from nuclear magnetic resonance (NMR) to drug design and analysis and quantum mechanics. Its research objectives are to develop novel

Biomedical Magnetic Resonance Facility at UWS. Image courtesy of University of Western Sydney.



Nanomics platform technology – bead on bead. Image courtesy of Nanomics Biosystems Pty Ltd.

experimental (especially NMR-based) techniques and theoretical models for studying molecular association, organisation and dynamics, and functional nanomaterials. The Group conducts fundamental and applied research in collaboration with CSIRO (Commonwealth Scientific and Industrial Research Organisation), the National Science Foundation in Sri Lanka and major petroleum companies in new energy technologies and with the Australian Nuclear Science and Technology Organisation (ANSTO) and groups in France on synthesis and applications of self- assembling organic/inorganic nanohybrids incorporating chiral functionality.

Another primary research focus is nano-biotechnology and medical nanotechnology. The Group is conducting a number of research projects to develop and extend NMR methodology to better probe biomolecular association (for example protein-protein self-association and ligand-protein binding).

Nanosonics Ltd is a life sciences company focused on the development of safe, non-toxic and rapid infection control and decontamination products. The company owns intellectual property relating to a unique disinfection and sterilisation technology using a proprietary biocide called NanoNebulant. These novel droplets of biocide can provide disinfection and sterilisation solutions for a range of infection control challenges.

Nanosonics has custom designed a device for disinfecting ultrasound transducers. Ultrasound is a diagnostic medical imaging technique used to visualise the size and structure of muscles, tendons and many internal organs. Ultrasound devices are considered semi-critical medical devices requiring high-level disinfection. Nanosonics' disinfection process fulfils occupational health and safety requirements, addresses material compatibility issues and provides a low toxicity and faster solution compared to conventional reprocessing methods. Nanosonics' device is simple to operate, achieving high levels of disinfection in less than five minutes. The entire process operates in a closed system, is environmentally-friendly and leaves no harmful residues – the only by-products are small quantities of water and oxygen. Nanosonics' first product is specifically designed to reprocess ultrasound transducers for the health care market and is due to be launched in late 2007.

Flinders University's Nanostructures and Molecular Interactions Research Group (NMI) works on molecular assembly processes, nanostructure development, and the regulation and manipulation of molecular processes. The NMI is developing new nanostructured materials with superior properties for applications such as biosensors, biochips, biomaterials and drug delivery.

Nanotechnology Victoria (NanoVic) was formed as a consortium dedicated to the industrial exploration of nanotechnology. Founding members include Monash University, RMIT University, Swinburne University and CSIRO (Commonwealth Scientific and Industrial Research Organisation). NanoVic also works with a variety of other research providers across Australia. NanoVic has conducted more than 60 projects in the last three years and established relationships with many of Australia's leading technology-based corporations.

NanoVic will be establishing two new companies around therapeutics and diagnostics and imaging. Therapeutics products under development include transdermal nanoparticle delivery for large molecule drug delivery across the skin; pulmonary nanoparticle delivery for large molecule drug delivery into the lungs; liquid crystal delivery for crossing biological membranes, including plant cell membranes; and in-cell modification of protein-based drugs at the genetic level.

The consortium is also developing diagnostics and imaging products including nanoparticulate diagnostic systems for human and animal health, antibody and binding reagent based simple diagnosis by Surface Plasmon Resonace Effects, NanoArray diagnostic biochips for high sensitivity laboratory-based diagnosis in human and animal health applications, a nanoparticulate enzyme biosensor for real-time measurements in biological and food-related sensing, and nanoparticle-based diagnostic imaging for the in vivo detection of early disease in human health.

PolyNovo Biomaterials Pty Ltd develops a range of biocompatible and biodegradable polymers for use in medical devices from transdermal drug delivery to bone repair procedures. The company is an operating division of the listed company Xceed Biotechnology, and works with technology that was developed over five years at CSIRO (Commonwealth Scientific and Industrial Research Organisation).

PolyNovo's NovoSorb product is used as a bone cement and substitute, in periodontal reconstruction and adhesion, as a drug delivery coating and as a general medical adhesive and sealant. NovoSorb is biodegradable and does not damage surrounding tissue during the curing process because it does not generate heat. NovoSorb had positive results in animal trials for performance in bone and as a potential coating for coronary stents. PolyNovo has partnered with Medtronic, a large US medical device company, and is collaborating with the Industrial Research Institute of Taiwan. In addition, the company has a licence with Biomet, a large US-based medical device company.

The NovoSorb technology was awarded the People's Choice Award at the 2006 Excellence in Materials Innovation in Biotechnology and the Life Sciences Award by Future Materials, as well as the 2005 CSIRO Research Achievement Medal.

PolyNovo has formed a joint venture company called NovaSkin with a renowned Australian burns surgeon. NovaSkin will initially focus on development and early stage clinical evaluation of two products: the Easy Application Synthetic Epidermis (EASE), which is designed for use in superficial skin loss situations; and Biodegradable Temporising Matrix (BTM), which will be used to treat full thickness skin injuries such as burns and trauma.

Prima BioMed Ltd develops and commercialises immunology and cancer immunotherapy products. The company holds commercial rights to selected research from the Burnet Institute, formerly the Austin Research Institute. It developed a targeting system for vaccines and immunotherapy. DCtag is a 40 nm particle to which antigens from either cancer or infectious diseases can be conjugated to deliver the target antigen to a patient's immune cells. These activate the patient's immune cells to recognise and destroy the cancer cells or infection, while minimising damage to surrounding tissue and other negative side-effects. Successful animal trials are complete on colon tumours and breast cancers.

DCtag is also proving to be effective in the treatment of viral diseases (respiratory syncytial virus), malaria and foot-and-mouth disease. In addition, it has been shown to be the first adjuvant technology to activate both arms of the immune system generating T-cells and antibodies without unwanted side-effects.

Prima BioMed has commercial arrangements with Monash and Victoria universities, and international collaborations with the Pasteur Institute in France, Canadian-based biotechnology companies Biomira and Trillium Therapeutics, and the US-based Walter Reid Army Research Institute, Mersana Inc, Medarex and AstraZeneca.

The Sonoactuator by Seagull Technologies

pSivida Limited is a global bio-nanotech company that develops controlled release drug delivery therapies. The company has offices in Singapore, the UK and the US, and is listed on the US (NASDAQ), Australian (ASX) and Frankfurt (FWB) stock exchanges.

pSivida created the novel biomaterial BioSilicon™, a nanostructured form of elemental silicon that is engineered to create a 'honeycomb' matrix of pores. The silicon honeycomb structure biodegrades into harmless silicic acid, while slowly releasing drugs located within. Work on novel depot formulations demonstrates that drug release can be controlled over periods of days, weeks and months. The company is developing BioSilicon™ brachytherapy products, such as BrachySil™, as a new cancer treatment that delivers radioisotopes directly into the tumour. BrachySil™ is currently undergoing clinical trials for liver and pancreatic cancer.

pSivida has also expanded its product range to include drug delivery treatments for various eye diseases, developing the only two FDA approved sustained release back-of-the-eye treatments (Vitrasert® and Retisert™) for chronic eye disease. The next-generation product Medidur™, which is used to treat diabetic macular edema, is in phase III clinical trials.

The **Queensland University of Technology (QUT)** is working with orthopaedic surgeons and biologists on surface modification and nanostructuring materials for composite bone substitute materials.

Seagull Technologies is developing a platform, non-invasive drug delivery device using an innovative combination of nanotechnology and ultrasound. The device consists of two unique components. The SonoActuator is a reusable handle that contains the system electronics and drug delivery indicator. The SonoPod is a disposable sterile gel pack that combines the drugs to be delivered. The design incorporates nanotechnology to ensure the drugs are delivered only when triggered by the switch on the SonoActuator. The ultrasound assists the rapid and controlled passage of the drug into the tissue. The device will initially be tailored for eye treatment with the production of the SonoEye. The SonoEye will provide a painless, rapid and accurate means of administering drugs to the back of the eye without the need for an injection.

Established in 1997, **Sirtex Medical Ltd** aims to become the world leader in liver cancer treatment products. The company developed SIR-Spheres®, biocompatible radioactive microspheres containing radioactive yttrium (a beta emitter) to target liver tumours. These unique microspheres are injected into the patient's bloodstream and become trapped in the small blood vessels of the tumour. The SIR-Spheres® then irradiate the tumour by a process known as Selective Internal Radiation Therapy (SIRT), destroying the tumour while most normal liver tissue remains relatively unaffected. SIR-Spheres® is approved for commercial use in Australia, the European Union, Hong Kong, India, Malaysia, New Zealand, Singapore, Thailand and the US.

Sirtex Medical is also developing Thermospheres® technology for targeted hyperthermia therapy. Thermospheres® will be used to destroy cancerous tumours by raising their temperature by some 5°C. The company has two subsidiaries in the US, Sirtex Medical Inc and Sirtex Wilmington LLC, and one in Europe, Sirtex Medical Europe GmbH.

Starpharma Holdings Ltd is a world leader in the development of dendrimer nanotechnology for pharmaceutical, life-science and other applications. Dendrimers are manufactured, nano-sized compounds with unique properties that make them useful to the health and pharmaceutical industry as enhancements to existing products and as entirely new products.

Starpharma Holdings' lead development is VivaGel™, a vaginal microbicide gel designed to prevent the transmission of Sexually Transmitted Infections (STIs), including HIV and genital herpes. VivaGel™ has successfully completed a phase 1 human safety trial and a number of line extensions are now planned, including condom coatings. The company is exploring the use of dendrimers in other medical areas including cancer, ophthalmology and targeted diagnostics. Starpharma Holdings is also actively investigating industrial applications of dendrimers, such as in the electronics, oil and plastics industries.

Starpharma operates a research network throughout Australia, Europe and the US. Through the company's US wholly-owned subsidiary Dendritic Nanotechnologies Inc, it has close relationships with major corporations such as Dow Chemical Company and Sigma-Aldrich.

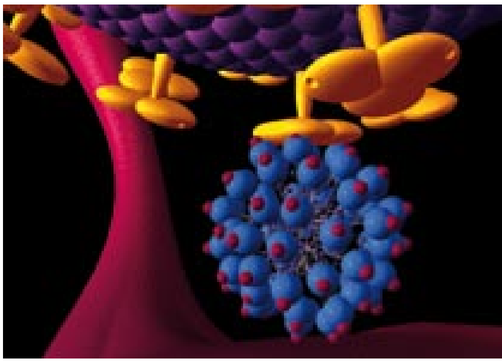
The **School of Chemistry and Physics** at the **University of Adelaide** undertakes research into biomolecular structure, function and interaction. Particular attention is being paid to molecular chaperones, a group of proteins involved in preventing other proteins from aggregating. When bound to polymer surfaces, the chaperone proteins function to inhibit protein aggregation, which means they can potentially be used in the treatment of protein aggregation diseases, for example, in the removal of accumulated protein deposits in long-term dialysis patients. The research is being undertaken in collaboration with the Ian Wark Research Institute at the University of South Australia, the University of Cambridge in the UK and the University of Canterbury in New Zealand.

The School is also collaborating with the Australian National University, researching host-guest chemistry to study the encapsulation by cyclic sugar molecules (cyclodextrins) of other molecules. Some of these captured molecules are activated upon light exposure to produce a conformational change, providing the opportunity to use them as nanodevices. As part of this research, in partnership with Princeton University in the US, cyclodextrins are attached to polymers for use in a variety of nanotechnological applications.

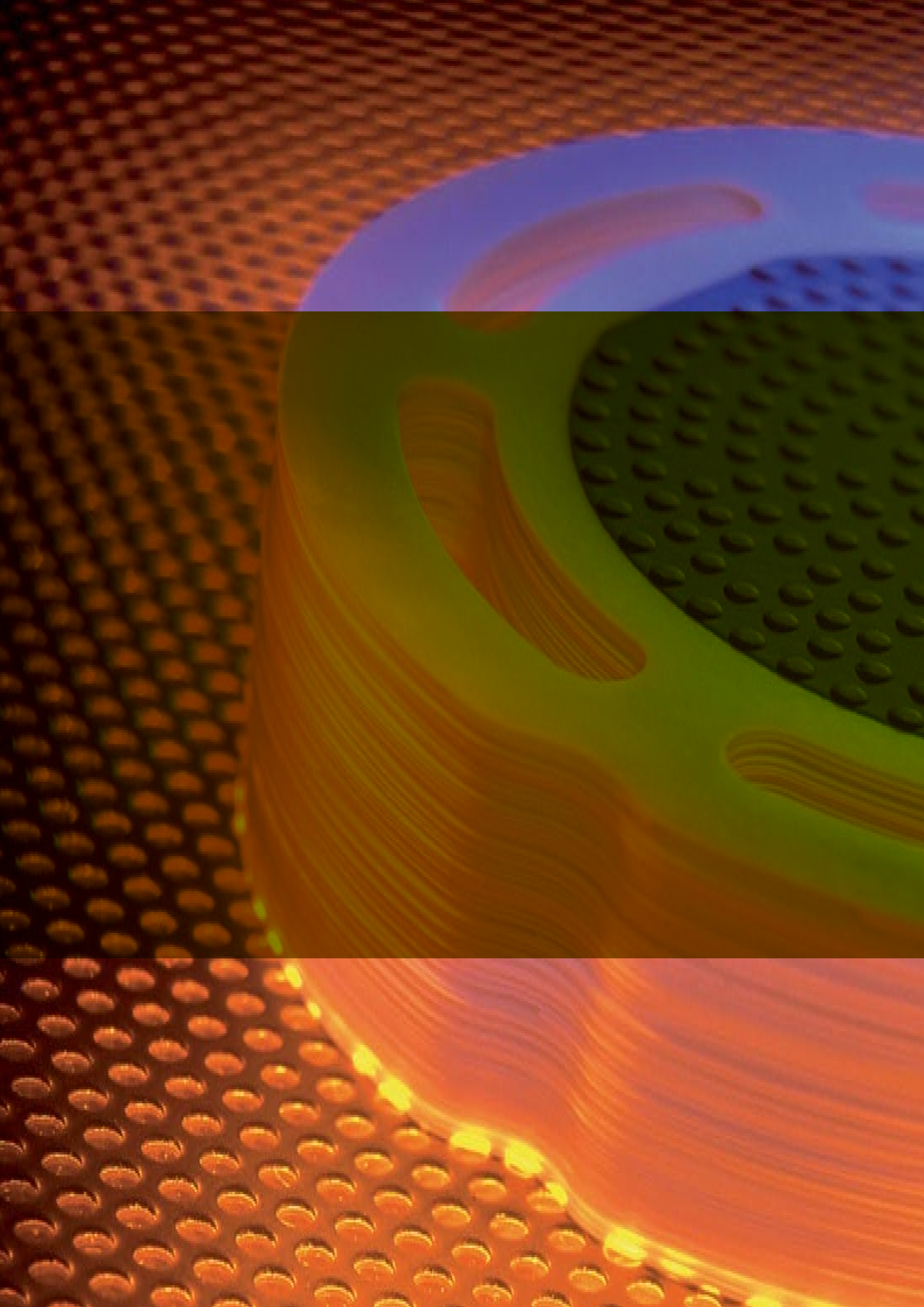
Research in this area uses a broad range of biophysical and spectroscopic techniques to characterise the biomolecules and their interacting molecules, for example, high-resolution, multi-dimensional NMR spectroscopy, circular dichroism, UV/visible and fluorescence spectroscopy, transmission electron microscopy and ultracentrifugation techniques.

The **School of Chemistry** at the **University of New South Wales** is exploring multiple nanotechnology projects into molecular devices where molecular building blocks are used to add functionality to surfaces and materials at the nanoscale. Nanobiosensors for the detection of analytes of interest in biomedicine, environmental monitoring and biowarfare agents are a major focus. The School is collaborating with the Schools of Physics, Materials and Chemical Engineering.

In another program, researchers are developing smart surfaces that allow manufactured materials to interface with biological systems in a highly controlled way, creating the next generation of biomaterials. The development of molecular devices that exploit electronic and magnetic properties of nanoscale objects is another priority. This research includes the synthesis of molecular switches and nanoscale conducting sheets, the functionalisation of nanoparticles and the development novel molecular wires and rectifiers.



Starpharma's dendrimer SLP7013 bound to HIV surface protein. SPL7013 has been shown in laboratory studies to prevent infection with HIV and HSV-2 (genital herpes). Image courtesy of Starpharma.



Energy and Environment

Australia enjoys a proud reputation for excellence in environmental sciences and research. The nation's experience in natural resources industries, addressing water scarcity and working across diverse climatic conditions makes it the perfect place for investment in environmental nanotechnology.

The country undertakes advanced research across a wide range of energy-related and environmental nanotechnologies. Early commercial success has already been achieved in supercapacitors and solar energy research. Nanotechnology-based energy storage and fuel cell technologies are moving swiftly through the development and commercialisation pipeline.

Australia is also skilled in developing and commercialising environmental and water-treatment nanotechnologies. Research ranges from new forms of industrial absorbents to nano-engineered filters for waste water and chemical streams, bio-degradable "plastics" and energy-efficient building materials.

Astute Nanotechnology is the commercialisation company for the **Australian Research Council (ARC) Centre of Excellence for Functional Nanomaterials**. Research groups from the Australian National University, the University of New South Wales, the University of Western Sydney and the University of Queensland comprise the Centre of Excellence. Astute Nanotechnology was formed when the four universities agreed to commercialise the Centre's intellectual property by forming the company in a strategic relationship with **UniQuest Pty Ltd**, the main commercialisation company of the University of Queensland.

Astute Nanotechnology and the ARC Centre of Excellence for Functional Nanomaterials have identified clean energy, the environment and healthcare industries as areas in which nanostructured materials will have significant early impacts. Clean energy production and utilisation will focus on gas to liquid conversion, hydrogen production and storage, fuel cells, and high energy density batteries. The environmental focus is on photocatalytic reduction of pollutants in water and air, economic removal and recovery of organic vapours, greenhouse gas reduction and utilisation.

Australian Membrane Technologies (AMT), an ANSTO spin-off company, is commercialising nano-particulate membrane bioreactor (NMB) technology for wastewater treatment. NMB offers superior performance in wastewater treatment compared to municipal systems with savings of up to 60 per cent in water reuse. It is also significantly cheaper to operate.

The **Research School of Chemistry** at the **Australian National University** has produced large surface-area films with appropriate adhesion. The School has since prepared and tested three optical devices. These include a device for environmental bioremediation (TiO_2 film on glass substrate) which involved the titania photocatalytic activity in the visible part of the spectrum of mesoporous nanocrystalline photoactive titania thin films being enhanced by nitrogen doping with thiourea. The films showed photocatalytic activity in the blue region by monitoring the photodegradation of methylene blue upon irradiation with a He-Cd laser working at 442nm. The second device involves hydrogen production by splitting water (TiO_2 film on silicon substrate). A film, around 3000 Å in thickness, splits water when irradiated by ultraviolet light and sunlight. The experiment, using heavy water, released deuterium and hydrogen deuteride from the system. The structure of this type of film was revealed by analysing a film less than 1000 Å in thickness deposited on silicon during calcination in vacuo using X-ray reflectometry. The results are compared with the film fired in air that was used to split heavy water. The final device is a light-to-electricity production (TiO2 film on conductive ITO substrate) that involves the assembly of a dye-sensitised solar cell (DSSC) in which the anode was constructed from a TiO_2 anode using the optimised synthetic route. A preliminary study of the sub-micron thick mesoporous TiO_2 film indicated an efficiency ~0.02 per cent.

The **Australian Research Council Centre of Excellence for Functional Nanomaterials'** research programs focus on the novel synthesis, characterisation and application of functional nanomaterials such as nanoparticles, nanotubes, thin films and nanoporous and nanocomposite materials. These materials are constructed by self-assembly at the nanometre scale (1–100 nm) and possess improved properties to make ideal materials for adsorbents, catalysts, sensors, fuel cells and battery systems. They are also attractive for biotechnology applications due to the controlled effectiveness of protein material, cell material, and tissue material interactions.

The Centre is specifically interested in clean energy production and use, including gas to liquid conversion, hydrogen production and storage, fuel cells, and high energy density batteries. It is also interested in environmental technologies such as photocatalytic reduction of pollutants in water and air, economic removal and recovery of organic vapours, greenhouse reduction and use. Healthcare focus areas include biomaterials for orthopaedic and cardiovascular applications and tissue repair.

Partners include the University of Queensland, University of New South Wales, the Australian National University and the University of Western Sydney. The Centre's aim is to create platform technologies for products in the fields of bioengineering and nanotechnology, with a strong focus on bringing products to market through its commercialisation arm, **Astute Nanotechnology**. Some international collaborators include: Carbon Nanotube Centre, Chinese Academy of Sciences, China; Forschungszentrum Julich, Germany; The Nanopartices Lab, Swiss Institute of Technology, Switzerland; Centre for Nanoscience and Nanotechnology, Georgia Tech, US; University of California at Santa Barbara, US; Particle Engineering Research Center (PERC) at the University of Florida, US; University of Washington, St Louis, US.

A "Ceramic Fuel Cell" - Anode and electrolyte cells. Image courtesy of Ceramic Fuel Cells.

CAP-XX Pty Ltd develops and manufactures high-surface area, electrical double-layer capacitors known as supercapacitors. The company is a global industry leader in power density technology by combining high capacitance and low internal resistance in a thin and flat package. Its work has recently been recognised by the World Economic Forum, having been selected as one of its Technology Pioneers for 2005. High-power energy storage devices enable manufacturers to make smaller, thinner and longer-running products such as cell phones, PDAs, medical devices, and power tools. CAP-XX products received Green Partner Certification from Sony Corporation, a necessary step for all companies supplying components to Sony. CAP-XX also received Frost & Sullivan's 2005 Technology Innovation Award for research that led to breakthrough nanotechnology for producing supercapacitors to meet the pulse-power requirements of portable devices. CAP-XX has principal offices in Sydney, Australia; South Carolina, US; and London, UK. Some of Cap-XX's international partners include Intel and Acer Polar Twin Advance of Malaysia. CAP-XX has major global customers in ruggedised PDAs, PC card/CF/USB and GSM/GPRS modems, and is addressing major opportunities for mobile phones, camera flashes and audio.

The **Centre for Sustainable Energy Systems (CSES)** at the **Australian National University** has been researching SLIVER solar cells. Origin Energy, the energy services retailer that funded the research, has completed a pilot manufacturing plant in Adelaide and is undertaking post-production testing prior to a commercial release. SLIVER solar cells address two of the fundamental barriers to greater uptake of solar electric technologies: the cost of electricity from solar; and the global shortage of ultra-high purity silicon used in high-efficiency solar cells. SLIVER cells are typically 80mm long, 1–2mm wide and 50µm thick.

Electricity prices from SLIVER technology will be competitive with the retail price of electricity from the electricity grid. SLIVER technology will also reduce the impact of the global shortage of hyper-pure silicon by using as little as one-tenth the amount of silicon compared with conventional solar cells. Solar panels made from SLIVER cells are lightweight, partially light-transmissive, can be flexible, are naturally resistant to internal cell temperature increases and are tolerant of partial shade.

Ceramic Fuel Cells Ltd (CFCL) develops solid-oxide fuel-cell (SOFC) technology that provides reliable, energy-efficient, high-quality, low-emission electricity from widely available natural gas and renewable fuels. CFCL is developing SOFC products for small-scale (up to 5 kW) on-site micro-combined heat and power (m-CHP) and distributed generation units that co-generate electricity and heat for domestic use. CFCL is using nanopowders to create thin films for interface layers and functional layers. The company has developed demonstration and prototype NetGen™ 1kW m-CHP units for collaboration with selected utilities and appliance manufacturers in order to integrate the SOFC technology into household appliances. These units have been awarded the European 'CE' safety approval mark. CFCL and its partners are conducting field trials in Australia, New Zealand and Germany. The company has also entered into product development partnership with Gaz de France and De Dietrich Thermique, and has formed a range of partnerships and collaborations with commercial engineering and nanotechnology companies, including CSIRO. CFCL was formed in 1992 and is publicly listed on both the London Stock Exchange AIM market and the Australian Stock Exchange (code CFU).

The **Cooperative Research Centre for Coal in Sustainable Development (CCSD)** provides research support to the Australian black-coal production and power industries. The Centre's products and services are underpinned by fundamental and applied research to understand coal's performance in current and advanced technologies, improve environmental performance and inform the strategic decisions of regulators and industry. CCSD's research program includes a number of projects that use nanotechnology, such as the investigation of zeolite production from coal ash for bulk use in agriculture. Zeolites are microporous solids with well-defined structures that are routinely used in many applications. CCSD is developing a process to produce a low-grade zeolite for use in agriculture as a controlled-release fertiliser to supply nutrients to plants on demand, substantially increasing efficiency relative to traditional fertilisers and reducing nutrients leaching into the environment. In addition, CCSD is also conducting research into high-temperature membrane reactors, which could potentially be used in gasification systems for hydrogen production and separation. Films of interfacing catalyst on suitable substrate are being developed to improve both the productivity and separation efficiency of hydrogen from the water gas shift reaction products.

The **Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE)** aims to protect human and ecological health by developing new methods for preventing contamination of soil, water and air. The Centre undertakes fundamental and applied research by integrating expertise in analytical and environmental chemistry, soil science, microbiology, toxicology, biotechnology, hydrogeology, engineering, modelling and material science. CRC CARE has a strong research focus on the potential use of nanotechnology to eliminate toxic waste from the environment and develop novel sensing technologies for contamination monitoring. The Centre's nanotechnology research includes the development of chemical and bio-nanosensors for detection of organic and heavy metal contaminants; engineered nanomaterial and catalysts for in situ degradation of contaminants in groundwater, air and soil; and bioengineered nanosystems based on novel catabolic micro-organisms and enzymes for environmental remediation. **CRC CARE Pty Ltd** was formed by CRC CARE to develop and commercialise its technologies.

The **Cooperative Research Centre (CRC) for Polymers** is developing specialty polymers for a wide range of applications in the biotechnology, manufacturing, mining, agricultural and energy sectors of the economy. It conducts research in four key areas: biomedical polymers, advanced polymeric materials, polymers for sustainable development, and engineering and design. Participants in the CRC include 10 universities, CSIRO (Commonwealth Scientific and Industrial Research Organisation), the Australian Nuclear Science and Technology Organisation (ANSTO), 10 companies and the Australian Stem Cell Centre. The Centre is developing technology to produce an all-plastic, light and flexible solar cell that will be more economical than silicon cells.

Nanotechnology plays an important role in controlling the design and structure of the polymeric components and the other specialised ingredients required to produce an all-plastic solar cell.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) is investigating whether synthetic and natural nanoparticles that enter natural water systems are bio-available and toxic to sensitive aquatic biota, either via direct cellular uptake or through accumulation in the food chain. The initial focus is on nanoparticulate metal oxides.

The environmental fate and pathways of nanoparticles in soils is also being studied to determine their potential as vectors to transport nutrients, ameliorants and biocides to plant roots, enhancing the productivity of potentially infertile soils.

The research builds on CSIRO's internationally recognised work on the chemistry, bio-availability and toxicity of metal contaminants in both aquatic and terrestrial systems. This research has played a major role in defining Australian and international regulatory guidelines for contaminants in these environments.

CSIRO has worked closely with Australian start-up company CAP-XX to develop and commercialise the world's most advanced high-power, small-form supercapacitors. Supercapacitors are high surface-area electrochemical capacitors that store a large amount of energy and can be charged/discharged very quickly (in a matter of seconds).

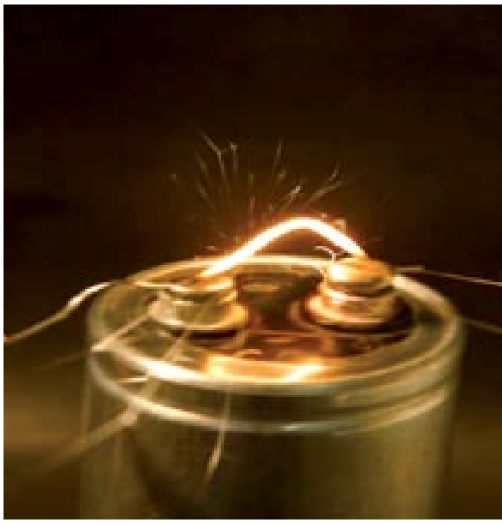
CSIRO is now targeting the development of high-energy supercapacitors based on novel electrode materials and electrolytes that exhibit improved material use and performance. Carbon and metal oxide-based nanostructured/nanoporous electrode materials are being developed and characterised for applications in next-generation 'asymmetric' supercapacitors that offer the potential to deliver high power and energy in a single, long cycle-life device.

Dyesol Ltd is a nanotechnology and renewable energy company that has become the industrial research hub for the world's network of researchers into Dye Solar Cell (DSC) technology. Dyesol researches, develops and manufactures Dye Solar Cell materials, components, and laboratory and manufacturing equipment.

DSC employs nanotechnology to create biomimetic processes, the most advanced third-generation solar technology. In DSC the dyed titania nanoparticulate electrode mimics photosynthesis in plants. Like trees, DSC thrives in variable light conditions in which other photovoltaic technologies struggle. The Dyesol team has an extensive patent portfolio and also works closely with the Swiss Federal Institute EPFL, Queensland University of Technology and University of Western Australia.

Dyesol and Corus, one of the world's largest rolled-steel manufacturers, have entered into a collaborative development program to develop a steel-based building product using Dyesol's DSC technology. This strategic collaboration, which is financially supported by the UK's Department of Trade and Industry, is aimed at the commercialisation of low-cost steel-based Building Integrated Photovoltaic (BIPV) products and, if successful, will be a major advance in the quest to create energy-neutral buildings. DSC is particularly suitable for the urban and city environments because, unlike conventional solar cells, it does not need direct light to produce electricity.

Dyesol subsidiary **Sustainable Technologies International Pty Ltd** has been contracted by the Australian Defence Science and Technology Organisation (DSTO) to demonstrate flexible solar panels based on Dye Solar Cell technology to provide portable and sustainable energy. Flexible DSC



Supercapacitor developed by CSIRO. Image courtesy of CSIRO.

panels hold promise for mobile applications such as powering, cooling, communications and sensors, either as light-weight mobile powerpacks or integrated into field structures. Dyesol has been listed on the ASX since August 2005. It has subsidiaries in Switzerland, the UK and Singapore.

Flinders University is working on industry projects to remove methosero in tallow products and to dissolve biodiesel into diesel's components without causing crystallisation. Other projects aim to increase the efficiency of dye solar cells currently on the market and develop a new type of dye-sensitised solar cell using ordered molecular organisation to make a more energy-efficient solar cell.

In conjunction with Ocean Power Design in Scotland, Flinders University is researching new ways of working with membranes to reduce the energy input used in desalination processes. Nanofiltration allows for larger pore sizes but, by maintaining selectivity using specific chemical functionalities to stop salts getting through, improved membranes are made. New reverse osmosis membranes are also being investigated in collaboration with two US universities.

Hydrexia Pty Ltd, a spin-off company from the University of Queensland, is commercialising hydrogen storage technology based on novel magnesium alloys. Hydrexia's proprietary materials store high densities of hydrogen (up to 7wt%) safely (in low pressure and in solid form) and, critically, at low cost. The materials are manufactured using long-established casting techniques, making them low-cost and easy to scale up to commercial quantities. Hydrexia is initially targeting large, off-board, hydrogen storage applications such as on-site industrial storage and is building prototype storage systems as the next stage in its development.

The **Ian Wark Research Institute (The Wark™)** at the **University of South Australia** is the **Australian Research Council (ARC) Special Research Centre for Particle and Material Interfaces**. It is also the headquarters of the Australian Mineral Science Research Institute (AMSRI), a virtual institute embracing outstanding research teams at the University of South Australia, the University of Melbourne, the University of Newcastle and the University of Queensland. The Wark™ conducts research on minerals and materials. Its underlying theme is particle and material interfaces.

The Wark™ conducts a blend of fundamental and applied research across a broad range of industry sectors and research areas including: minerals processing; interparticle forces and adhesion; wetting and particle adsorption; nanotechnology and nanolubrication; biotechnology; bio and polymer interfaces; biomedical and biodental implants; pharmaceutical; metals; ceramics; composite materials; surface modification and coatings; surface engineering; molecular modelling; computational colloids; food; pigments; and the environment, including mine site remediation.

The Wark™ research projects include: new water quality and treatment procedures using tailored nanoparticles; novel techniques for water treatment using functionalised surfaces that remove organic matter and pathogens and can desalinate water without the need for electric energy; and optimising tailings dewatering through interfacial chemistry and particle interactions. Most of the projects are performed in close collaboration with Australia's mining and water industries and international partners.

With over 100 active research projects, major clients include Anglo American Platinum Corporation, BHP Billiton, Bridgestone Australia, Cytec Industries, Kodak, MIM Holdings, Newcrest Mining, Newmont Australia, Philips National Research Laboratories, Rio Tinto, Schefenacker Vision Systems Australia, Sola International, Teck Cominco, Unilever and WMC Resources.

The **Monash Institute for Nanosciences** brings together a large array of nanoscience research and development expertise from across **Monash University**. Its range of expertise covers medicine, pharmacy, chemistry, physics, engineering, mathematics, food sciences and materials. Researchers undertake basic and applied research at the nanoscale with a strong multi-disciplinary focus.

The Institute is conducting research into nanoscience-based technologies impacting on the environment in areas such as alternative energy production, clean and green manufacturing, environmental sensing, light metals and composites, corrosion reduction, water quality management, bio-engineering and fuel storage. A research project on green chemistry processes, including novel toxic solvent replacement processes that can potentially reduce the environmental footprint of known synthetic processes, such as reducing energy requirements, is also being carried out.

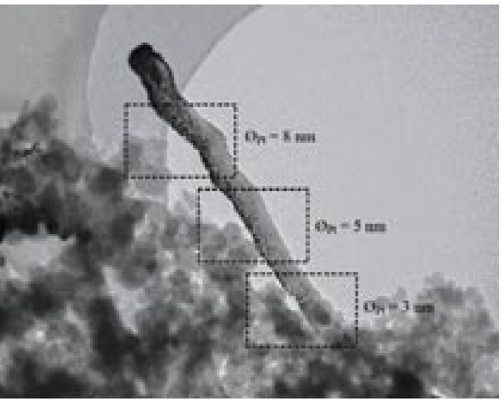
Other projects include the development of a novel solar cell system that can be incorporated into existing systems to potentially improve output, components for fuel cell systems and light metals that reduce the weight of metals used in transport and construction without compromising functionality.

The **Murdoch Applied Nanoscience Research Group (MANRG)** at **Murdoch University** has a cluster of ongoing applied nanoscience research projects. In the area of environmental pollution control, it is collaborating with the largest fertiliser manufacturer in Australia, Burrup Fertiliser, to investigate the use of nanoFe (ferrofluids) in the battle against fertiliser run-offs.

Murdoch University's Murdoch Energy Science Group has a strong focus on photovoltaics, focusing on q-dots manufacture and Si nanowire synthesis by chemical vapour deposition (CVD). In addition, the Group has pioneered the production of aligned carbon nanotubes (CNTs) by CVD and a dedicated nanocarbon CVD system will be built by the end of 2007.

NanoChem Holdings Pty Ltd is commercialising a decade of research from the University of Queensland and other Australian research institutes into silver catalysts for formaldehyde production and a new ion exchange waste-water treatment process. NanoChem's patented silver catalyst has optimal properties that facilitate maximum performance during the formaldehyde production process. Typically, formaldehyde yield is increased, methanol conversion enhanced and formation of by-products inhibited. In addition, NanoChem supplies a unique technical service and support package to ensure formaldehyde producers outstanding results. NanoChem's ion exchange water treatment product removes up to 100 per cent of ammonium ions present in a range of contaminated waters with up to 150 mg/l ammonium concentrations. The ammonia-rich solution that is produced is then either disposed of by private contractor or air-stripped and reused. No other waste products are created. The silver catalyst is in full-scale production and the water treatment product is completing pilot plant testing in Sydney and the UK. NanoChem has clients in Australia, China, Central and East Asia, South America, the UK and the US.

NanoQuest Pty Ltd aims to commercialise innovations in the field of nanotechnology through strategic investment in nanotechnology research and intellectual property development on projects with sound commercial potential. It has a strong focus on novel nanoparticles for photocatalytic water purification and nanoporous silicon membrane molecular sieves for hydrogen purification for fuel cells. This research is moving out of development and into the commercialisation process, based on technology from the University of Queensland.



Carbon nano-fibre coated with platinum nano-aggregates of various diameters (ØPt). Image courtesy of Australian National University.

NanoQuest has a worldwide exclusive licence to: the Metal Oxide Nanoparticles (MOP) technology platform, which has applications in indoor air purification and industrial odour clean-up; advanced chemical catalysis and potable water clean-up, including the cryptosporidium bacteria; ultra-pure water treatment for modern industrial plants; and industrial gas and vehicle oxygen sensors. Markets for these applications are estimated at $200 million per annum. The company's revenues are sourced from sub-licensing MOP, manufacturing and selling MOP ultra-fine powders and reactive membrane filters for air purifier markets.

Nanotechnology Victoria (NanoVic) was formed as a consortium dedicated to the industrial exploration of nanotechnology. Founding members include Monash University, RMIT University, Swinburne University and CSIRO (Commonwealth Scientific and Industrial Research Organisation). NanoVic also works with a variety of other research providers across Australia. NanoVic has conducted more than 60 projects in the last three years and established relationships with many of Australia's leading technology-based corporations.

In June 2006, NanoVic played a major role in the GAP Forum on Commercialising Nanotechnology in Water, during which Australia's most pressing water issues were identified and discussions were carried out on the use of nanotechnologies to address and aid the water issues currently facing the nation. NanoVic is currently involved in a number of water sector projects, including the detection and clean-up of water sources. Three of these projects focus on the analysis of contaminants such as heavy metals, nutrients and toxins in environmental waters. These include the development of NanoArrays Biochip, Nanoparticulate Enzyme Biosensor and Surface Enhanced Raman Spectroscopy (SERS) Nanostructured Probe. These technologies will allow for rapid, sensitive and accurate detection of contaminants in water, both within the laboratory and as portable instrumentation in-field. In partnership with the Melbourne Aquarium, NanoVic is demonstrating and promoting water recycling and reuse using nanotechnology. This project is saving the Aquarium up to 10,000 litres of water a week.

Plantic Technologies produces novel biodegradable polymer nanocomposite material based on seven years of research at the Australian Cooperative Research Centre for International Food Manufacture and Packaging Science. Plantic manufactures, under a worldwide exclusive licence, environmentally-friendly starch-based polymers that have the look, feel and flexibility of conventional plastic. Made from corn, the material is rapidly biodegradable, can be coloured and is suited for a variety of plastic conversion processes such as thermoforming, injection moulding, film extrusion and blow moulding. The product is being used by Cadbury Australia and is supplied to 80 per cent of the Australian chocolate tray market.

The company is focused on making its products stronger and cheaper than conventional plastics and is extending its application to pharmaceutical products, including blister packaging for drugs. Plantic is developing other applications for this technology, including nanoclays, high modulus materials and improved barrier applications. The technology has been classified as compostable to European Standards and the company has offices in Europe.

The **Queensland University of Technology (QUT)** is working with Dyesol Limited to improve the performance of the cathode structures of dye-sensitised solar cells (Graetzel cells). QUT researchers are also developing a low-cost alternative to photovoltaics that is constructed from a thin film of composite material, a mixture of carbon nanotubes and a conductive polymer.

The aim of the project is to develop power production with zero greenhouse gas emissions by direct photovoltaic conversion of sunlight into electricity, without high production costs. In this project, funded by the Asian Office of the American Air Force (AOARD), the polymer (poly-3-hexylthiophene) forms the matrix of the heterojunction composite solar cells. The carbon nanotubes are added to the polymer, increasing conductivity. Dyes can then be added to the system to increase the light absorption and increase the efficiency of the system. In collaboration with Louisiana State University in the US, QUT is studying different kinds of doped nanotubes for conductivity improvements.

Researchers at QUT are also working on the production of hydrogen and oxygen from water using solar energy and a light activated catalyst. They are developing methods such as sensitisation and ion implantation to extend the response of these materials into the visible region of the solar spectrum and attain higher energy conversion efficiencies.

QUT is working to prepare and characterise light metal-based nano-composites for hydrogen storage. The Mg–Ti37.5V25Cr37.5 composite, which has a high hydrogen storage capacity and excellent absorption/desorption properties, was successfully prepared by reactive mechanical alloying (RBM). It can be *in situ* activated during the milling. The hydrogen capacity is over 3.8 wt% even at 373 K, and one absorption/desorption cycle can be finished in 20 minutes at 543–573 K.

QUT researchers have developed a novel titanium material for fabrication of an environmentally friendly product to purify water. The material can be used as either a powder or deposited as a coating, thereby avoiding the need for filtration from the water. The material has an extremely high surface area, found to be 28–120 m2g-1. QUT is designing a continuous flow water purification process with potential application for specific air purification needs.

QUT has collaborated with researchers in China and Belgium to develop techniques for synthesising various nanorods of anatase (TiO_2) copper oxide, rare earth oxides, iron oxide and niobate by hydrothermal reactions. These nanostructures exhibit interesting electrochemical, catalytic, ion exchange and adsorption properties. Highly efficient photocatalysts that can work under visible light irradiation have been developed from the one-dimensional nanostructures.

QUT has developed a world-first innovation by designing ceramic membranes known as nanomesh that can filter tiny particles including viruses from liquids, such as blood and water. The ceramic nanofilters were constructed with a hierarchically structured separation layer on a porous substrate using larger titanate and smaller alumina nanofibres. This approach is based on the latest developments within nanostructures of metal oxides. The resulting membranes can effectively filter out species larger than 60 nm at flow rates that are in orders of magnitude greater than conventional membranes and are inherently 'immune' to the structural deficiencies (cracks, pinholes and serious sintering) of conventional ceramic membranes. Because of the high filtration efficiency and low fabrication cost of these membranes, they have potential for a broad range of applications in the dairy, food, pharmaceutical, bioengineering, chemical, nuclear energy, water-treatment and electronic industries.

The **School of Applied Sciences** at **RMIT University** focuses its research on nanocatalysts for the conversion of carbon dioxide into more useful chemicals to lead to process technique improvements in petroleum and related industries. Other research projects include the investigation of processes of biogenetically synthesised gold nanoparticles and their application in drug delivery. The School receives collaboration and support from Alcoa World Alumina and BHP Billiton for the development of novel bi-functional materials for removing mercury from condensate, modification of gold surfaces for sensing mercury in alumina gaseous effluents and removal of mercury from alumina refinery wastewaters. It has fully-equipped, state-of-the-art facilities to carry out innovative research in this field.

The **Short Wavelength and Interactions with Materials Group** at **Macquarie University** is developing a platform technology for producing short-pulsed, high-peak power and high-efficiency lamps based on dielectric barrier charges. Its research includes exploring these sources for application in environmental technology, particularly water purification, and decontamination through the destruction of harmful bio-organisms in soil, water and air.

The **Space Plasma, Power and Propulsion Group** at the **Australian National University** has played a significant role in the semiconductor industry in developing new high-density plasma sources and their application to innovative thin film deposition. Currently, the group is focusing on the hydrogen economy sector, developing a new generation of proton exchange membrane (PEM) fuel cells. The group is investigating the manufacture of efficient PEM fuel cells based around plasma processing techniques. In comparison to typical wet chemical processing of materials, plasma processes are clean, dry and efficient. Several plasma processing techniques are being used to make fuel cells a more viable alternative energy source for the future. In fuel cells, platinum plays a crucial role but also makes them very expensive. The group has shown that the amount of precious metals used for the catalyst (such as platinum) in PEM fuel cells can be significantly reduced using plasma-sputter deposition while increasing fuel cell efficiency at the same time. In a new development, the group has developed a single plasma system that can deposit carbon nano-fibres and coat them with platinum nano-clusters for improved fuel flow electrodes. Furthermore, the group is implementing a plasma discharge to synthesise polymer membranes that are thin, dense and highly cross-linked, allowing a complete plasma fabrication of the heart of the fuel cell.

The **University of Technology, Sydney (UTS)** has developed nanotechnology-based light pipes of various kinds. These can be used to transmit natural or artificial light around a building or a consumer appliance and have the advantage of being efficient and cool in operation. The running costs of this technology are so low that in some circumstances it is uneconomical to install a light switch to turn it on and off. The technology has now been licensed to an Australian manufacturing entity and is being commercialised. It has immediate applications in commercial and emergency lighting, and office-based general lighting may be only a few years away.

Viva Blu Pty Ltd was established in 2006 to develop and commercialise a photocatalysis nano-technology for industrial and municipal water treatment plants. The company's proprietary technology removes trace quantities of harmful organic molecules and micro-organisms that manage to escape traditional filtration processes in multi-barrier water treatment plants. Key market applications include municipal drinking water treatment, environmental and recreational water body remediation, and industrial influent and effluent.

The Viva Blu™ technology eliminates the need for treatment chemicals, does not produce dangerous chemical by-products, performs consistently and has a lower capital cost, and substantially lower annual operation and maintenance cost. The growing acceptance and demand for environmentally-friendly technology provides a strong market opportunity for the Viva Blu™ technology.

Electronics and Photonics

Australia is contributing to the integration of electronic and optical technologies and the creation of new products with significant market potential through applications such as computing and communications systems, software, assembly, power delivery and micro-architecture (circuits).

Areas of Australian expertise include the development of new plasma sources for manufacturers of focused ion beams; compound semiconductor quantum dot-based lasers; infrared directors and integrated optical circuits; silicon-based photonics; and optical integration to increase the speed of computers.

Other technologies under development include light emitting diodes; fibre-optic applications; ultrahigh-bandwidth devices for optical systems; silica and polymer planar waveguides; optical fibre fabrication; thin film fabrication; and fibre Bragg gratings.

The **Department of Electronic Materials Engineering (EME)** at the **Australian National University** conducts interdisciplinary research in areas such as condensed matter physics, materials science, nanoscience and nanotechnology. The properties of nanoscale materials and the ability to understand, fabricate, manipulate and use such materials is a critical area of research for the Department. One project underway is researching quantum dot optoelectronics (the study and application of electronic devices that interact with light). Research in this area involves the studies of III-V semiconductor quantum dots (QDs). These studies range from the basic, such as epitaxy (the growth of crystals of one material on the crystal face of another material) and characterisation of these nanostructures, to device applications such as quantum dots lasers and infrared photodetectors.

EME is also investigating the thermal stability and the post-growth interdiffusion/intermixing of the QD structures to selectively modify their band gaps, to enable integration of devices of differing functionalities onto a single chip.

Another research project is investigating nanowires. The growth of GaAs, InGaAs, InAs, InP and GaSb nanowires is conducted at EME via the vapour-liquid-solid mechanism where gold nanoparticles are used to nucleate the one-dimensional growth on the semiconductor substrates. The size and shapes of these nanowires are dependent on growth temperature, which is typically 100–200°C lower than normal MOCVD growth. By varying the deposition conditions, both the axial and radial growth can be controlled. Very long nanowires (~10 µm) with diameters of a few tens of nanometres can be achieved with excellent crystallinity. Strong photoluminescence could also be observed from the nanowires. These nanowires are of great interest due to the possibility of using them as nanobuilding blocks (both active devices and interconnects) of future optoelectronics devices. Other research includes synthesis and characterisation of nanocrystals on silicon substrates for silicon photonics and nanoindentation of silicon for memory device applications.

The **Research School of Physical Sciences and Engineering** at the **Australian National University (ANU)** has extensive nanotechnology knowledge and experience. Major research and development expertise includes: electronic materials and devices; photonics and optical devices; lasers; plasma processing; surface physics and chemistry; atomic and molecular physics; plasma and nuclear physics; and accelerator mass spectrometry.

ANU's Space Plasma and Plasma Processing (SP3) Program has a new plasma source with the world's largest manufacturer of focused ion beams – the US company FEI Corporation. Focused ion beams are a workhorse for nanomanufacturing, enabling substrates to be cut to five nanometres in accuracy. Current focused ion beams use gallium, but this metal can affect the substrate being machined. ANU's plasma uses Xenon, which is inert and has no impact on the substrate. SP3 expects this work to soon result in a product with market potential to replace many thousands of existing plasma sources.

Research on atom lithography in the **Atomic and Molecular Physics Laboratories** at the **Australian National University** uses laser techniques to control and manipulate metastable helium atoms that can be used to pattern surfaces using similar processes as employed in UV lithography. The advantage of atom lithography is that it can surpass the diffraction resolution limit of optical processing but with lower throughput. ANU researchers are also making breakthroughs in compound semiconductor quantum dot-based lasers, infrared directors and integrated optical circuits. Researchers have enhanced the light-emitting structure of silicon by creating nanoscale structures called nanocrystals, with the aim of developing silicon-based photonics and optical integration to increase the speed of computers. The long-term goal is to commercialise high-performance, high-speed devices such as photonic integrated circuits based on quantum dots. Researchers are also investigating the creation of an entirely new nanoscale memory technology that takes advantage of a change in the composition of silicon structure under pressure. This work has led to the creation of a spin-off company, **Wriota**, to exploit its potential for commercialisation and has attracted the attention of Intel.

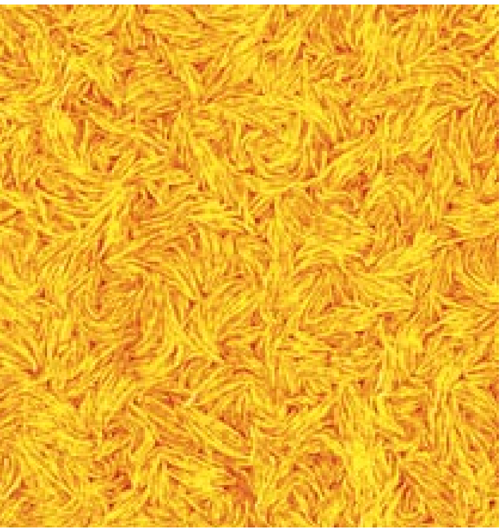
The **Australian Nuclear Science and Technology Organisation (ANSTO)** uses its new research reactor OPAL to irradiate silicon for international electronics manufacturers. The neutron flux produced in the reactor converts individual silicon atoms to phosphorus within the silicon ingots without damaging the crystal lattice to effectively 'dope' the silicon and hence change its electrical conductivity.

The **Australian Research Council Centre of Excellence for Antimatter-Matter Studies (CAMS)** is a collaboration of Australian universities and research institutions that studies the interactions of antimatter with different types of matter, from single atoms to biological molecules, surfaces and materials. Its research program brings together some of Australia's top scientists from a broad range of disciplines.

CAMS studies solid surfaces and thin films using variable energy positron beams. The basic work involves the improvement of positron moderation and beam production, which has applications for scattering of variable-energy thermalised positrons from thin films, surfaces and the interfaces for metals and semiconductors as insulators. The aim is to explore the effects of absorbed gases on the materials and to characterise defects and voids in materials. CAMS is interested in the development of its unique instrumentation and its potential applications in other applied research and industrial fields, particularly at the single atom and monolayer level.

The **Australian Research Council Centre of Excellence for Coherent X-ray Science (CXS)** aims to obtain the structure of proteins, such as the pharmacologically important group of membrane proteins, which have proved difficult to measure using standard crystallographic techniques. The method pursued by CXS researchers is to focus an intense beam of X-rays on a sample and measure the diffraction pattern. While challenging to implement in biological samples, the CXS approach has been demonstrated in materials-type samples such as metal nanostructures. A key feature of this approach is providing 3-dimensional imaging at resolutions below 20nm, something that is not possible by other methods.

Researchers at La Trobe University comprise two of the five nodes of CXS, including the Experimental Physics Program which has direct capabilities relating to nanotechnology. These capabilities include electron beam lithography, sputtering and reactive ion etching. Researchers are active in the fabrication of nanoscale optical devices and in the attachment and patterning of protein structures to surfaces. Key capabilities in fabrication are electron beam lithography at 100 nm line widths and protein attachment and patterning; and imaging below 20 nm resolution with 3-dimensional reconstruction.



Self-assembling in silica nanohybrid thin films for ion-exchange separations. Image courtesy of Australian Nuclear Science and Technology Organisation (ANSTO)

The **Australian Research Council Centre of Excellence for Photovoltaics** aims to advance silicon photovoltaic research and apply these advances to the related field of silicon photonics. The Centre comprises five research teams that are investigating novel ways of improving the efficiency and cost of silicon-based photovoltaic and photonic devices. One of the Centre's projects is researching silicon-based nanostructure tandem cells. Tandem cells are stacks of individual photovoltaic cells with different energy thresholds that each absorb a different band of the solar spectrum, usually connected in series. This project aims to engineer a new silicon-based material to form a top cell above a silicon cell. This material is 'engineered' using a quantum dot nanostructure of silicon in a silicon-based dielectric matrix.

Bandwidth Foundry specialises in direct-write photolithography foundry services including photomask production and direct laser writing of optical materials. Its expertise lies predominantly in the areas of precision lithography, PDMS lithography (stamps), greyscale lithography, interferometric lithography and photonics. The company also provides contract engineering (prototyping and R&D) services for the development and proof-of-concept stages for customers. In conjunction with a major European technology company, Bandwidth Foundry is developing a novel nanopatterning technology for 2-dimensional interferometric lithography (2DIL) for very high-speed writing of super-fine structures. This can be used for a diverse range of large substrates including 12-inch wafers and 1 m^2 panels, with the materials ranging from silica to curable sol-gel polymers. 2DIL is a unique process based on multiple-beam interference that overcomes the resolution and phase noise limitations of traditional mask lithography. It will outperform commonly used scanning laser methods and electron beam lithography in terms of the combination of writing speed, feature size and pattern precision. The 2DIL platform can be used in a number of diverse applications such as planar gratings, patterning of photonic band gap materials, 2-dimensional phase masks and photomasks for flat panel displays.

The **Centre for Atomic, Molecular and Surface Physics (CAMSP)** at the **University of Western Australia** has an international facility comprising spin-polarised electron-pair (e,2e) spectroscopy and single electron spectroscopies such as low-energy electron diffraction (LEED), Auger, electron energy loss spectroscopy (EELS), X-ray photoelectron spectroscopy (XPS), ultraviolet photoelectron spectroscopy (UPS) and spin polarised low-energy electron diffraction (SPLEED). It also has an optical ellipsometer and crystallography and microscopy facilities. The Centre specialises in combining these techniques to establish a better understanding of many surface phenomena.

The quantum phenomena of electron exchange and spin-orbit interaction for polarised electrons scattering from atoms, particularly the transition metal atoms of interest to thin film magnetic materials, is another key area of study. The current instrumentation development is to attach an electron spin analyser to a JEOL Scanning Electron Microscope, the first such instrument in Australia.

CAMSP is interested in developing its unique instrumentation and its potential applications in other applied research and industrial fields, particularly at the single atom and monolayer level.

The **Centre for Lasers and Applications (CLA)** at **Macquarie University** has major projects encompassing micro and nanostructuring materials using laser processing. It is working on the laser fabrication of microphotonic optical systems (for example planar lightwave circuits, integrated optical devices) and fundamental studies of laser/matter interactions. These projects are supported by programs developing advanced characterisation techniques such as

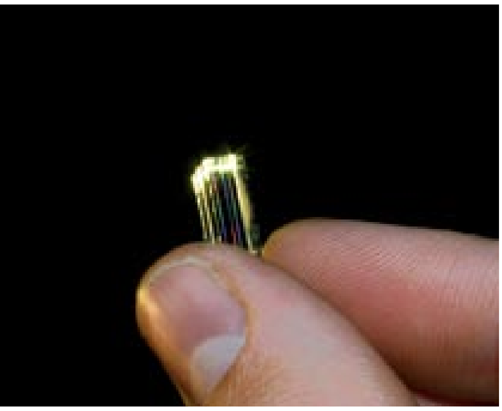
3-dimensional particle imaging using multi-wavelength pulsed coherent light sources, near-field optical probing and nanoscale optical microscopy. CLA provides R&D support for Laser Micromachining Solutions (LMS), supplying precision laser microstructuring capability to Australian industry, universities and Lighthouse Technologies and developing medical laser products.

The **Centre for Micro-Photonics (CMP)** at **Swinburne University of Technology** was established in 2000 and became the Melbourne node of the Australian Research Council Centre of Excellence for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS). CMP is also a founding member of the NanoVic Network and a partner of the Australian Cooperative Centre for Polymers. CMP researches and develops photonic devices in sub micro- and nanoscales. Research programs include: nano-optics (investigating the light interaction with quantum dots and nanoparticles, quantum electrodynamics for near-field scattering, and near-field optics); nanometry (super-resolution microscopy, near-field microscopy, laser trapping and tweezers, imaging and manipulation of quantum dots and nanoparticles, single molecule dynamics and micro-cavity dynamics) and nanophotonic devices (multi-dimensional nanophotonic data storage and drives, nanomachines and motors, nanobiochips and nanophotonic fabrication). CMP features a world-class nanophotonics facility, equipped with a polymer and nanoparticle laboratory and a Class 2 biology laboratory. The uniqueness of this facility lies in the integration of polymer and nanoparticle fabrication, biology, ultra-fast laser technology and high-resolution optical microscopy and spectroscopy. CMP has created a revolutionary instrument based on the concept of near-field tweezers, capable of measuring ultra-weak force (femtonewton to piconewton) and torque. This instrument will allow the possibility of nanoprobes for single molecule dynamics and molecule structuring.

The **Centre for Organic Electronics** at the **University of Newcastle** is a new initiative focusing on the development of new electronic devices at the intersection between semiconductors and plastics. It focuses on the scientific challenges in the development of organic photovoltaics, which has massive potential for the next generation of environmentally-friendly energy sources, photonics and biosensors. The Centre's new Nanostructure Deposition Facility provides unique capabilities in nanotube and organic electronic device fabrication. Through a partnership with CSIRO's (Commonwealth Scientific and Industrial Research Organisation) Division of Energy Technology, the Centre is capable of taking fundamental research through to large-scale fabrication and evaluation.

The **Centre for Technology Infusion** was established at La Trobe University's R&D Park to develop and transfer industrial technology, research, intellectual property (IP), design services and industrial products to the community in the micro and nano fields. The Centre's overall goals are to engage in strategic and translational research; provide design and test services; provide access to technologies, electronic design automation tools, infrastructure and methodologies for research and product development; transfer research and innovations to public and private sector markets; and support the development of industries in strategic and key growth areas.

One of the Centre's research foci is the development of a wireless smart sensor based on micro/nanotechnology. It aims to create intelligent nanosensors to detect, identify, process and transmit information with applications to the ICT, health, energy and environment sectors. The Centre will bring together highly integrated nanoelectronic devices and interconnection



These rainbow optical pathways are wavelength selective and have been inscribed inside a block of glass using an ultrafast laser fabrication system by Dr Graham Marshall as part of his research for the Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS). Image courtesy of CUDOS, Macquarie University.

technology for system-on-chip integration and wireless networks; nanocircuits with ultra-high integration density and very low power consumption; highly integrated multi-sensor sub-systems driven by high-performance nanotechnology actuators; and micro/nanoelectronics with photonics and micro-electro-mechanical systems (MEMS) technologies.

The Centre has established industry standard infrastructure for micro/nanochip design and testing. It has research and product development facilities based on high powered workstations supporting industry standard EDA tools, as well as access to a test facility based on the Agilent 93000 SoC tester. This facility provides leading-edge capabilities that address the most complex testing, IP validation and characterisation challenges.

The **Centre for Ultrahigh bandwidth Devices and Optical Systems (CUDOS)** is a research consortium between five Australian universities: the University of Sydney, Macquarie University, University of Technology Sydney, Australian National University and Swinburne University of Technology. CUDOS also has international collaborations with Bell Labs and OFS Laboratories in the US and Osaka University in Japan.

The CUDOS research program has two central themes: micro-photonics and nonlinear photonics. The aim of achieving ultra high-speed all-optical signal processing on a single photonic chip is addressed by combining these two themes to develop micron-scale photonic components incorporating nonlinear photonics processes.

The Centre has active research programs in photonic circuitry, microstructured optical fibres, 2-dimensional and 3-dimensional photonic crystals, and photonic devices and applications, as well as strong programs in nonlinear optical theory, modelling and simulation. In addition, there are experimental programs in the fabrication of micro-structured guided-wave optical devices and studies of nonlinear optical effects in periodic guided wave geometries. CUDOS has a comprehensive set of test and measurement capabilities, including a 160 Gb/s optical bit error rate test (BERT) system.

The **Centre of Expertise in Photonics** is located within the School of Chemistry & Physics at the **University of Adelaide**. The Centre works closely with the Defence Science and Technology Organisation (DSTO) to develop new classes of optical fibre for defence applications. The Centre also collaborates closely with other academic groups nationally and internationally and with defence industry companies. The Centre's research can be applied to sensing, biotechnology, proteomics and for the detection of pathogens in water.

The Centre has set up a complete suite of fabrication and experimental capabilities that allows it to translate new concepts in soft glass fibres through to world applications. The research activities include: optical glass development and fabrication; glass extrusion for structured preform development; soft glass fibre fabrication; microstructured fibre design; fabrication and glass flow modelling; novel non-linear fibre development; in-fibre proteomics and DNA analysis; fibres for chemical sensing; fibres for mid-IR laser delivery; and fibre laser development.

Also with the **School of Chemistry & Physics** at the **University of Adelaide**, research is being undertaken into the design and synthesis of new materials that show unusual optical or electronic properties. Current projects include compounds that may be used as molecular wires (nanowires) or as optical limiters. Since unsaturated carbon chains are attached to selected transition metal-ligand groups, the chemistry involves organo-metallic synthesis and requires the development of new synthetic methodologies. The new materials are characterised by a combination of spectroscopic methods (IR, NMR, UV-visible, MS) and crystal structure determinations, while the electronic properties are probed by appropriate physical techniques, such as electrochemistry. The research is carried out in collaboration with computational and synthetic groups in France and Germany.

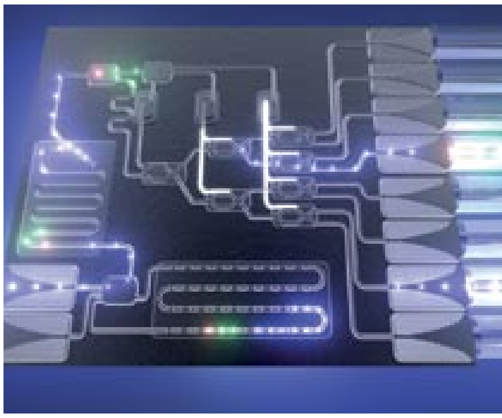
Other fundamental research by the School of Chemistry & Physics includes: the structure and reactivity of transition metallo-organic molecules using laser, molecular beam and mass spectrometric techniques; using quantum computational methods such as ab initio and density functional theories to calculate structures and properties of transition metallo-organic molecules; and the study of the spectroscopy and photodissociation dynamics of various aldehydes of importance to atmospheric chemistry (in collaboration with the University of Sydney).

CSIRO (Commonwealth Scientific and Industrial Research Organisation) has developed ink-jet printable electronic devices based on gold nanoparticle-organic hybrid materials and special post-processing to produce highly conductive structures on plastic and paper. Currently the focus is on the printing of multi-layer structures of passive and active components such as conductors, resistors, capacitors and sensor transducers. Patented applications include printed antennas, chemical sensors and wireless sensors.

The **Defence Science and Technology Organisation (DSTO)** is part of Australia's Department of Defence. DSTO ensures the expert, impartial and innovative application of science and technology to the defence of Australia and its national interests. DSTO is involved in the development of techniques and devices that span a 1 nm to 1,000 nm scale. The Organisation has a growing number of projects involving the application and use of nanotechnology in sensors and actuators, and to modify the properties of materials. DSTO also has nanotechnology and micro-engineering facilities.

Iatia Limited is a leading wavefront imaging company with visualisation and measurement applications in nanotechnology, the life sciences, ophthalmology and defence. Its unique Quantitative Phase Imaging™ (QPI™) technology, which was originally developed at the University of Melbourne, enables the real-time imaging of otherwise invisible objects by adding shape and form to an image. QPI™ uses traditional imaging technology, such as digital cameras (meaning no special optical components are required), to extract phase and wavefront information. In effect, QPI™ provides a digital phase contrast solution to transmission imaging techniques at the nanoscale where few other contrast mechanisms are available due to fabrication difficulties for short wavelength radiations like electrons and X-rays.

Iatia has formed partnerships with companies including the US-based Xradia, which develops high-efficiency zone plate lenses for X-ray imaging, and Intel, to develop other micro-focusing applications. GE Healthcare has incorporated Iatia's technology into one of its cell analyser products, while in 2004 the Japanese electron microscopy specialist HREM released a new product capable of photographing the atomic structure of the base material of silicon chips to provide magnetic field maps using Iatia's technology. Iatia is seeking partners to incorporate its technology in the nanotechnology, defence, ophthalmology and life sciences fields.



Schematic of a photonic chip. Image courtesy of CUDOS, University of Sydney.

i-Glass Projects Pty Ltd is an Australian film technology manufacturing company that produces first-rate film technology with applications in the architectural, aerospace, multimedia and automotive industries. More than 10 years of research and development have culminated in a world-class manufacturing facility, with a Class 1000 clean room. The company's products include a switchable liquid crystal thin film that can be used in many glass products worldwide. The i-Glass film can be switched from opaque to clear by applying an electrical charge. The unique design of the liquid crystal matrix also provides a unique projection display surface that can be used in retail and multimedia applications.

The **Department of Physics** at **Macquarie University** hosts nanophotonics research, including the study of the nonlinear dynamics of quantum well and quantum dot semiconductor lasers, and integrated devices and systems with potential for application in communications and quantum information. Fundamental, physical nano-optics is explored in projects using micro-diffractive-optical elements to produce near fields with nano-structure that is visualised using laser processing techniques.

The Department is developing plasma-based photon sources emitting at vacuum ultraviolet (VUV) and ultraviolet (UV) wavelengths for use in materials science studies and as potential alternatives to ion beams and e-beams in nanolithography and related materials processing. Although some source parameters may be different, the large photon energy can be comparable with some synchrotron beam lines. The patented platform obtains high peak power operation from dielectric barrier discharges.

The Department's **Short Wavelength and Interactions with Materials (SWIM) Group** is developing a platform technology for producing short-pulsed, high-peak power and high-efficiency lamps based on dielectric barrier charges. The research includes exploring these sources for application to photon lithography with commercial applications in materials deposition and coating; UV curing such as the hardening of paints, lacquers and adhesives; surface treatment including surface etching and cleaning, printed circuit boards, glass substrates and the removal of organic residues; photo-chemistry for photo chlorination, photosulpho-oxidation and photo-oxidation; and photo-medicine.

The **Microanalytical Research Centre (MARC)** is a member of the Australian Research Centre of Excellence for Quantum Computer Technology, which is researching silicon, solid-state quantum computer devices. MARC supports an emerging international program on quantum diamond which resulted in a spin-off company called **Quantum Communications Victoria (QCV)**. The Centre also collaborates with CSIRO (Commonwealth Scientific and Industrial Research Organisation), the Department of Applied Physics at RMIT University, the Australian National University and international research groups.

MARC is conducting nanotechnology research in a number of areas, including ion beam lithography with high energy ions. This technology is used for writing high aspect ratio structures in materials, including exposure of single ion tracks at the 10 nm scale. The Centre's 5 MeV Pelletron accelerator produces ion beams, which are focused with nuclear microprobe systems. The ion beams from the 5 MeV Pelletron accelerator and associated microprobe systems are also being used to perform ion beam analysis of sub-micron scale materials and devices. Rutherford backscattering spectrometry is employed to analyse thin films, particle induced X-ray emission for trace element analysis and ion beam induced charge for mapping charge transport, and field distributions in semiconductor devices at the micron and submicron scale.

MARC is researching single ion implantation for the fabrication of quantum computer devices in silicon within the Centre of Excellence and investigating other devices that incorporate single-colour centres in photonic or electronic devices. The MARC also has clean room facilities for device processing, including optical lithography, e-beam evaporation, rapid thermal annealing, keV ion implantation, electron microscopy, Raman spectrometry, focused ion beam microscopy and, in late 2007, low-temperature electrical characterisation. These research capabilities support the major projects in the Centre for Quantum Computer Technology, diamond quantum devices, trace element analysis of upper mantle geology, fundamental materials science and advanced condensed matter theory.

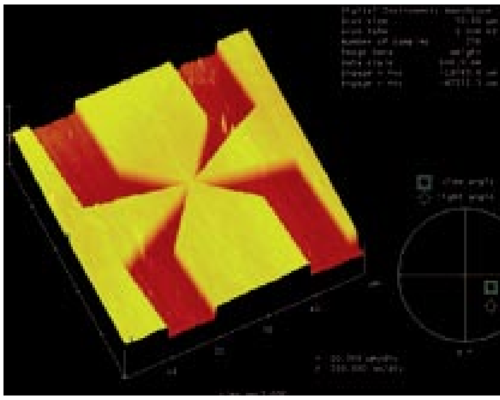
The **Microelectronics and Materials Technology Centre (MMTC)** at **RMIT University's** School of Electrical and Computer Engineering is investigating the design, fabrication, packaging and characterisation of a range of micro and nanoscale devices, including integrated optical, sensor, microfluidic, optofluidic, micro-electro-mechanical systems (MEMS) and radio-frequency (RF) devices. The MMTC has a strong capability in device fabrication technologies, including thin film deposition and etching, standard photolithography and clean room processing, as well as more novel processes such as nanolithography, soft and variable dose lithography, nano-imprinting, laser and mechanical micro-milling, and micro-contact printing.

Research in sensor technology focuses on surface acoustic wave-based liquid, gas and bio-sensors, conductometric gas sensors and micro-cantilever biosensors. Nanostructured thin films with nanopores, nanowires and nanorods are being developed for gas and biosensors with enhanced sensitivity. Integrated microthermoelectric devices are also being investigated.

The **MMTC's Integrated Optics Research Group** is investigating a range of planar optical waveguide devices. Research areas include broadband lithium niobate optical intensity modulators, resonantly enhanced optical modulators, polymer optical waveguides, soft imprinted waveguides, grating assisted directional couplers, integrated optical RF phase shifters, acousto-optic tunable filters and optofluidic devices, as well as the integration of wideband photonic and RF devices.

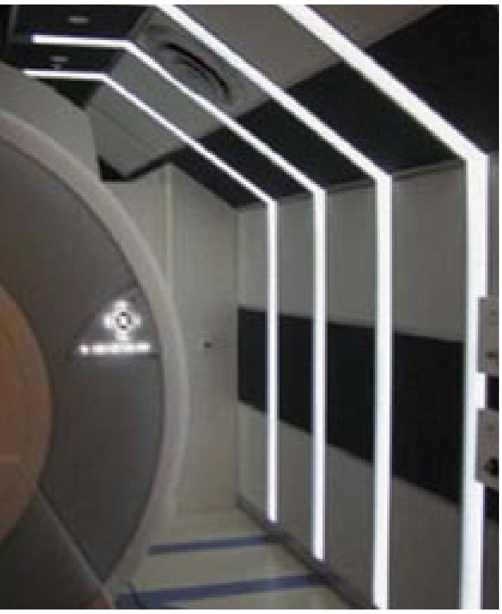
MiyoTech Limited is a fabless system module company with the objective of becoming the dominant supplier of next-generation lower power small form factor system products and technologies. The company is particularly active in the development of 3-dimensional information systems for next-generation information retrieval, high integration of silicon and low power use. MiyoTech has an office in California and strong research links with Stanford University in the USA.

The **Nanoscale Science and Technology Centre (NSTC)** at **Griffith University** has expertise in the fundamental theory of materials, materials development, sensing, microelectronic engineering and microtechnology, across the disciplines of physics, chemistry, biology, mathematics and engineering. NSTC investigates problems integral to the development of intelligent systems for the coming revolution in nanotechnology. These include the development of new sampling and sensing devices, next- and future-generation electronics and advanced functional materials, as well as gaining a better understanding of the fundamental nature of nanostructures and the 'micro-meets-nano' (M@NT) issues of scale. The Centre must address these latter issues as it progresses from microscale to nanoscale devices and systems.



Atomic force microscope image of a 400 nanometre wide semiconductor quantum wire fabricated at the University of NSW. Courtesy W. Clarke, O. Klochan & Alex Hamilton.

NSTC has research programs and opportunities for industry linkage projects in: nanostructures (the theory of nanostructures, mining nature, templating, nanowriting, hydrogen storage materials, nanomagnetism and spintronics); nanosensors (functionalised nanotubes for sensing applications); nano/microelectronics (silicon carbide (SiC) devices and silicon oxide (SiO_2) devices); nano/microfluidics; and Lab-on-a-Chip (analyte manipulation and nanofluidics theory). One of the Centre's current priorities is developing sensors for hazardous materials based on carbon nanotubes functionalised to confer chemical selectivity. NSTC is equipped to modify carbon nanotubes, fabricate microelectronic devices and integrate these as a Lab-on-a-Chip package.



Royal Melbourne Hospital using Poly Optics fluorescent alternative system. Image courtesy of Poly Optics Pty Ltd

Poly Optics Pty Ltd manufactures fibre-optic lighting for numerous applications in the construction industry. With the development of its patented Super Side Light technology, the company is able to provide a flexible, heat-free and energy-efficient solid-core fibre-optic cable designed to be illuminated with LEDs. This energy-efficient fibre-optic lighting system produces no heat, contains no fragile glass and lasts 10 to 20 years with little or no maintenance by radiating LED light over a distance of up to five metres. Architectural applications include flexible aisle and step-lighting systems for use in cinemas or comparable low-light environments. Poly Optics has developed products for use in hospital wards and nursing homes, such as illuminated bathroom and bedroom lighting. It has a project to replace fluorescent lighting in refrigerated drinks cabinets for the Queensland Government. In 1998 Poly Optics was awarded the largest fibre-optic lighting system project in the world, illuminating the 70-storey Cheung Kong Building in Hong Kong. Poly Optics is already well recognised in the lighting industry, having previously won several national and international awards, including the DuPont Award for 2005 and 2006.

Quantum Communications Victoria (QCV) is developing a prototype that will enable absolute secure communication using the quantum properties of light. The device is capable of producing single packets of light (photons) that can be transmitted in optical fibre. This device is a diamond-based, single photon source suitable for optical fibre-based quantum communications. Microscopic crystals of diamond are grown directly onto the tips of optical fibres, allowing the single photons emitted from the diamond crystals to be channelled directly into the fibre. The result is a robustly packaged, miniaturised and room temperature stable single photon source. QCV is working with the US military and Boston-based MagiQ Technologies in the USA and is seeking additional international collaborations.

The **Queensland University of Technology (QUT)** can fabricate at the nanoscale, produce prototype micro-electro-mechanical systems (MEMS) devices and nanostencils using its Dual Beam Focused Ion Beam Scanning Electron Microscope. It also has the capability to characterise nanoscale samples and explore the fundamental growth and electronic properties of ordered organic and inorganic nanostructures. These structures can then be used for nanoelectronic applications such as ultrahigh density memories and molecular transistors using a combination of scanning tunnelling microscopy (STM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

QUT is undertaking a project to control the quantum dot nucleation site to form ordered patterns of homogeneous nanostructures, implantation of Ga+ ions or in situ substrate patterning by STM. Other projects include the deposition of diamond-like carbon for electro-optic applications, electronic windows and the electrochemical synthesis of conducting polymers from biological precursors.

QUT is also conducting extensive experimental and theoretical investigations to establish theories and techniques for characterising thermal-mechanical performance of microelectronic, photonic, microstructured optical fibres and other microsystems by investigating the effects of materials mismatch, constraint and defects on failure mechanisms and establishing more sophisticated life prediction models. The outcomes can be used to create a knowledge base for materials properties and failure mechanisms for design, reliability evaluation and life prediction in micro-devices.

The **University of Adelaide's T-ray Group** established the world's first laser-based T-ray user facility in 2005. The facility runs a range of T-ray research programs mainly in the areas of biosensing, security and short-path communications. T-rays have potential applications in food safety and quality monitoring; disease detection; airport security; postal scans for drugs, explosives or bio-weapons; military threat detection; and medical diagnosis. The diagnostic ability of T-rays includes items that are smaller than the wavelength of the T-ray itself. For example, T-rays can be used to study human cells at the cellular level, DNA, proteins and nanomaterials.

The **School of Physics** at the **University of New South Wales** has built up major infrastructure for nanotechnology research. The School supports diverse research activities including atomic scale fabrication of silicon devices, fundamental studies of quantum devices operating at ultra-low temperatures, photonics and optical devices, protein crystallography, quantum computing, surface physics and spintronics.

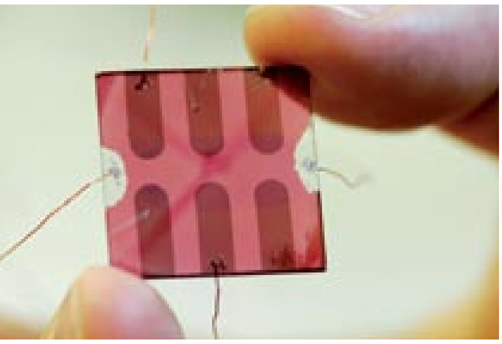
The **University of Technology, Sydney (UTS)** research into the characterisation and modelling of nanostructured soft magnetic material for advanced electromagnetic applications has commercial applications through the manufacturing of hi-tech, nanomagnetic materials and innovative smart devices and systems.

The **School of Electrical, Electronic and Computer Engineering** at the **University of Western Australia** is conducting research into superlattice-based nanostructures grown by molecular beam epitaxy (MBE) for infrared detectors, novel resonant cavity enhanced nanostructures for tuneable infrared detectors, quantum effects and transport properties of the 2-dimensional electron gas in AlGaN/GaN high-electron mobility transistors (HEMTs) and carrier transport and scattering in nanoscale silicon-on-insulator (SOI) structures for future nanoelectronics.

In collaboration with the Australian National University, the School is integrating quantum dot infrared photodetectors (QDIPs) with micro-electro-mechanical systems (MEMS) to produce wavelength-tuneable opto-electronic sensors. Other projects include using nanoporous silicon as an anti-reflection coating on micro-lenses, and creating novel distributed Bragg reflectors.

The University has strong research links in the nanotechnology area with several US universities and Wurzburg University in Germany. It also collaborates with Raytheon Vision Systems, Air Force Research Labs (AFRL) and the Defense Advanced Research Projects Agency (DARPA) in the US, and ENSERG/MINATEC in Grenoble, France.

Beauty and the beast: an advanced two-dimensional quantum semiconductor transistor being studied at the University of New South Wales. Image courtesy Professor M. Gal & A. Hamilton.



Organic photovoltaic cell produced at Queensland University of Technology (QUT) based on a blend of poly-3-hexylthiophene and carbon nanotubes. Image courtesy of QUT.

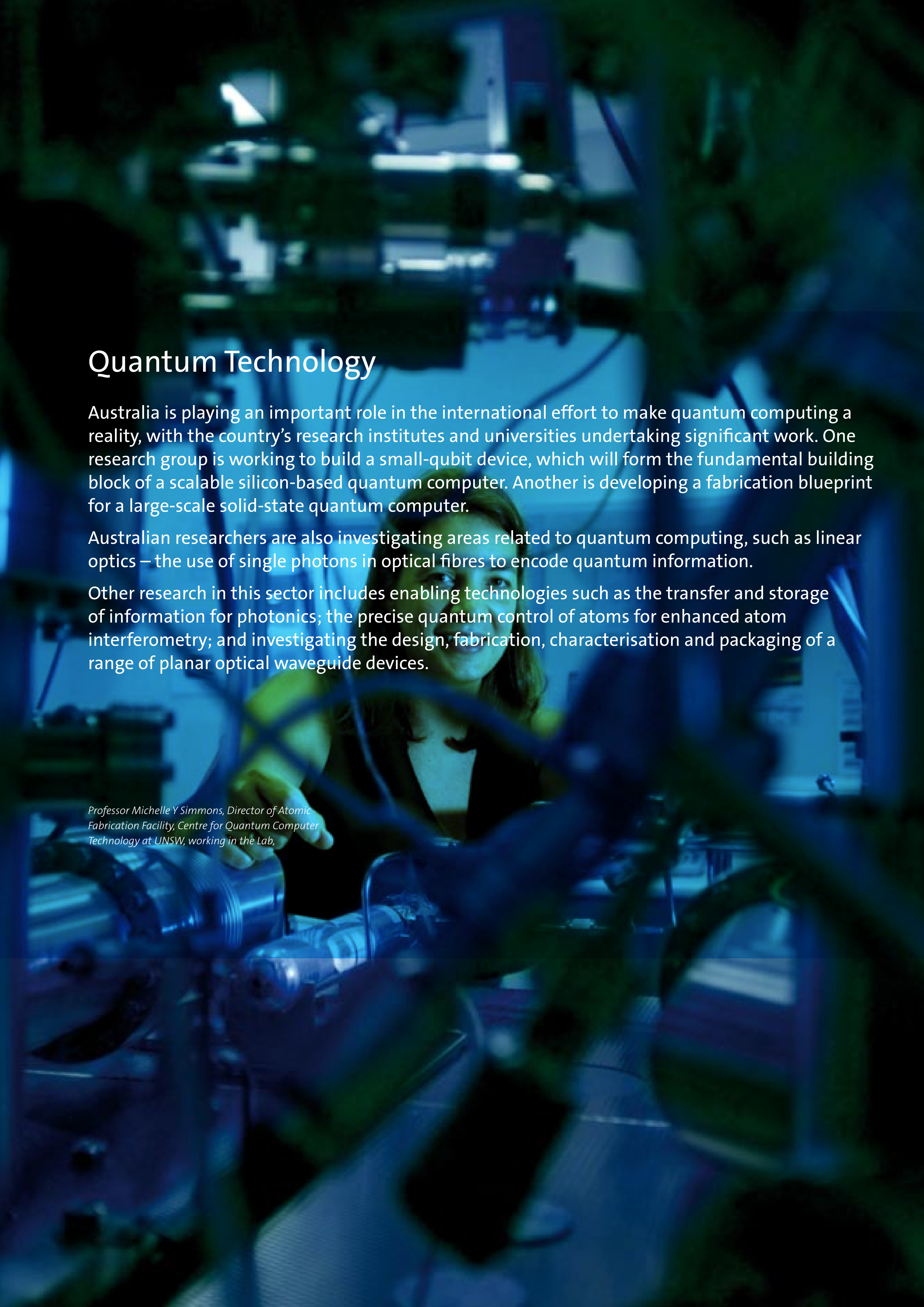
The **Western Australian Centre of Excellence for MicroPhotonic Systems (COMPS)**, part of the Electron Science Research Institute at **Edith Cowan University**, engages in fundamental and applied nanotechnology research and development. Research activities cover the areas of design, fabrication and characterisation of photonic devices based on magnetically reconfigurable integrated photonic nanostructures (magnetic photonic crystals). COMPS has recently implemented an RF Magnetron Sputtering Facility dedicated to the fabrication of advanced photonic nanodevices, such as arrayed high-speed optical intensity modulators, waveguide-integrated isolators and microresonators, photonic switches, magneto-optic sensors and complex magnetic photonic crystal structures. COMPS has an extensive range of nanofabrication process-related and photonic characterisation equipment suitable for the post-fabrication testing of advanced photonic devices. Through its established international research collaboration network with leading nanotechnology institutions, COMPS also has access to semiconductor, laser and nanophotonic fabrication facilities. The nanophotonic facilities at COMPS are suitable for the synthesis of new and advanced photonic materials that could lead to new science and new technologies.

Quantum Technology

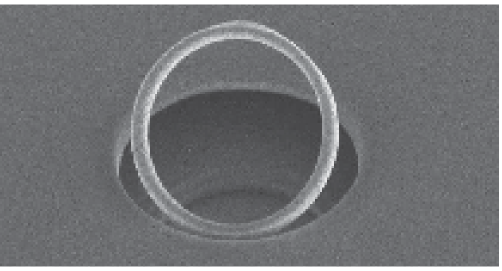
Australia is playing an important role in the international effort to make quantum computing a reality, with the country's research institutes and universities undertaking significant work. One research group is working to build a small-qubit device, which will form the fundamental building block of a scalable silicon-based quantum computer. Another is developing a fabrication blueprint for a large-scale solid-state quantum computer.

Australian researchers are also investigating areas related to quantum computing, such as linear optics – the use of single photons in optical fibres to encode quantum information.

Other research in this sector includes enabling technologies such as the transfer and storage of information for photonics; the precise quantum control of atoms for enhanced atom interferometry; and investigating the design, fabrication, characterisation and packaging of a range of planar optical waveguide devices.



Professor Michelle Y Simmons, Director of Atomic Fabrication Facility, Centre for Quantum Computer Technology at UNSW, working in the Lab,



The world's smallest diamond ring consists of a circular cavity that accidentally got disconnected on one side from the thin diamond substrate. Image courtesy of University of Melbourne.

The **Australian Research Council Centre of Excellence for Quantum-Atom Optics** aims to build a quantum toolbox to enable applications such as the transfer and storage of information for photonics, and the precise quantum control of ultra-cold atoms for enhanced atom interferometry. The Centre combines pre-eminent Australian theoretical and experimental research groups in quantum and atom optics, forming a powerful network to advance this rapidly developing field. The Centre is supported by the Australian Research Council, the Australian National University, Swinburne University of Technology and the University of Queensland.

The **Australian Research Council Centre of Excellence for Quantum Computer Technology** is headquartered at the University of New South Wales (UNSW). The Centre has key nodes at the University of Queensland and Melbourne University, while Griffith, Macquarie and Sydney universities and the Australian Defence Force Academy also participate. Research is aimed at developing cutting-edge nanotechnology, breakthrough results and an extensive patent portfolio embracing atom scale electronics and quantum computing. The US Government's Quantum Computer Technology Roadmap calls for a 100-qubit device to be created by 2012. The Centre aims to construct a small, nine-qubit device that will form the fundamental building block of a scalable silicon-based quantum computer. The Centre also plans to develop a fabrication 'blueprint' for a practical large-scale solid state quantum computer.

One of the Centre's key research programs is working to develop a phosphorous-in-silicon quantum computer, in which phosphorous atoms are placed into the lattice with atomic precision. Each of the atoms form a quantum dot or isolated quantum system. Metal gates are layered above to control the quantum dot. This is the world's first application of the fabrication technology, which has been perfected over the last five years. A major advantage of the Centre's work in silicon-based quantum computing is that incremental advances in technology can be applied now to the mainstream semiconductor industry.

The Centre is also working on hydrogen lithography to develop a more accurate method of inserting the phosphorous into the lattice. This will eventually allow the creation of atomic scale electronics. In parallel, the Centre is exploring complementary approaches to quantum computing that include linear optics, using single photons in optical fibres to encode quantum information. Researchers at the Centre have worked with colleagues at Johns Hopkins University and the University of Illinois in the US and the University of Vienna in Austria.

The **Centre for Nanoscience and Nanotechnology (CNST)** at the **University of Melbourne** fosters convergence in science and engineering to develop applications for biosciences, biotechnology and nanoparticle-based medicines and medical diagnostics. The Centre's flagship projects are quantum computing and nanoelectronics, quantum dot nanocomputing, tissue engineering, particle-based drug delivery and bio-labelling, and nanoengineered particle-modified surfaces.

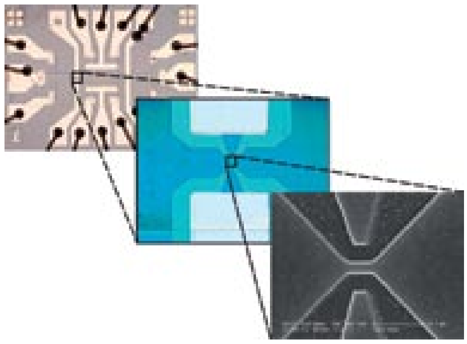
With more than 20 years in researching superconducting materials, devices and measurement, **CSIRO (Commonwealth Scientific and Industrial Research Organisation)** is the world leader in building Superconducting Quantum Interference Device (SQUID) systems for applications (*Nature Physics*, December 2006). This has been achieved by a multidisciplinary approach that encompasses all facets of the creation and realisation of superconducting systems from the materials development, theory and design, fabrication and testing, to measurements and system building with integrated electronics. For example, the CSIRO LandTEM system licensed to the manufacturer, Outer Rim Developments Pty Ltd, has been instrumental in the discovery and delineation of over A$6 billion worth of mines in Australia, Canada, Tanzania and the US.

CSIRO is developing superconducting nanostructures for nanoSQUIDs that can be used for nuclear magnetic resonance (NMR) of nanoparticles and clusters, single photon detection, qubits and other applications. CSIRO also develops quantum mechanical devices for a range of applications including qubits, absolute value detectors, magnetometers and gradiometers.

The **Laser Physics Centre (LPC)** at the **Australian National University** undertakes research and training on a range of topics with a balance between fundamental, strategic and applied laser-based research. The Centre's research program spans many aspects of contemporary laser physics and quantum electronics. Current research at the LPC is investigating quantum information processing using optical manipulation of nuclear and electron spin systems in solid state hosts. The materials of particular interest are rare-earth doped insulators and the N-V centre in diamond. Quantum information processing investigations use Raman processes to optically manipulate the spin state of the chosen system. The fact that optical manipulation and detection results in significant advantages when compared to conventional NMR has been important for many of the breakthroughs achieved at the Centre. Of particular note, the Centre demonstrated the first solid-state 2-qubit logic gate and developed techniques to realise the longest nuclear spin decoherence times achieved in solid-state systems. This has allowed significantly longer and higher-fidelity quantum memory demonstrations than previously possible.

The **Quantum Electronic Devices Group** at the **University of New South Wales** is investigating the fundamental properties of nanoscale electronic devices. Its areas of research include hole-based quantum devices, spintronics (devices that exploit the quantum mechanical spin of the electron or hole through the spin-orbit effect), quantum wires and quantum dots, and organic electronics. The Group uses the extensive nanofabrication facilities at the university's Semiconductor Nanofabrication Facility (SNF) to create these devices, while high-sensitivity electronic measurements are performed in dedicated cryogenic systems at ultra-low temperatures and in intense magnetic fields.

The Group has formal collaborations with the universities of Cambridge, UK; Copenhagen, Denmark; Oregon and Boise State, US; and Massey, New Zealand. It is also working with the Nippon Telegraph and Telephone Corporation (NTT) in Japan.



Optical and electron microscope images of a 200 nanometre wide quantum wire transistor fabricated at the University of NSW (courtesy W. Clarke & Alex Hamilton). This gallium-arsenide transistor uses holes, rather than electrons, to transport current through the narrow quantum wire shown in the bottom image.

Qucor Pty Ltd is a spin-off company that commercialises technologies developed at the Centre for Quantum Computer Technology, an Australian Research Council Centre of Excellence. Qucor's international partners include the US National Security Agency (NSA), the US Department of Defense and major US IT corporations. Qucor manipulates individual atoms and photons to create next generation products for computing and communications. The company is supported by the technical expertise and infrastructure of the Centre for Quantum Computer Technology, the largest such centre in the world in terms of staff numbers and funding. The company's patented scanning tunnelling microscopy and ion-implantation techniques allow a semiconductor with a precise number of dopant ions to be implanted in a precisely ordered layout or array. As a result, transistor size can be reduced, more can be integrated onto a single chip and the threshold voltage uniformity and reliability can be improved. This unique technology enables the development of quantum computers capable of performing numerous simultaneous functions.

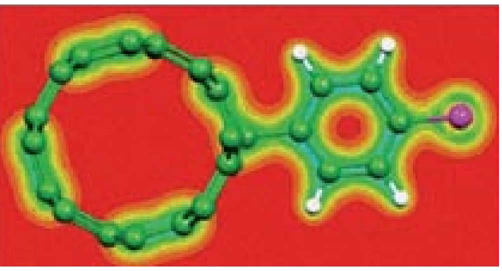
Instrumentation and Software

Australian organisations are developing instrumentation and software solutions that assist nanotechnology research and development in Australia and overseas.

Examples include metrology devices for microelectronics and sensors; innovation in photonics manufacturing, research and prototyping facilities for companies wanting to take their development beyond proof-of-concept and into early-stage manufacturing; and software imaging enhancement solutions for visualisation, wavefront sensing and machine vision.

The activities of Australian companies and institutions are supported by national research infrastructure, including major national research facilities. These facilities are significant nodes of scientific instrumentation, information and expertise, and are a key reason why the country is a provider of nanotechnology instrumentation and software.

X-ray phase contrast image of bone showing fine trabecular and growth structure. Field-of-view 2mm. Image taken on an XRT PCX2-50 X-ray system at 40kVp using a TruFocus source and a PSL VHR imager. Image courtesy of XRT Ltd



Modelling image of charge density-diaznoium on SWCNT, developed by The Centre for Computational Molecular Science (CCMS). Image courtesy of CCMS, University of Queensland

Artimech Pty Ltd has close associations with universities and companies at the forefront of technology development. The company focuses on providing the instrumentation, services and products to support the development of advanced technology. It also develops products for other companies and, in some cases, these products have been based on nanotechnology that others have developed but required more general electro-mechanical design solutions. Artimech specialises in materials selection; engineering design and analysis and tolerancing; 3-dimensional and 2-dimensional computer-aided design modelling, testing, development and manufacture of products; and custom-designed machinery. To more closely align its business with microtech and nanotech industries, Artimech now shares premises with MiniFAB, an Australian micro and nanotech business, and has been actively involved in designing many of the electro-mechanical devices MiniFAB sells. Examples of specific areas of work include Formula 1 and V8 supercar design and sensor development for the Department of Defence.

The **Australian Research Council Centre of Excellence for Complex Dynamic Systems and Control (CDSC)** is linked to the University of Newcastle and the Queensland University of Technology. The Centre works on complex systems such as applications for mine production and transportation systems, process control and optimisation and electromechanical systems, including nanotechnology and robotics, to optimise their performance. The Centre's mechatronics program is working with the Laboratory for Dynamics and Control of NanoSystems (LDCN) at the University of Newcastle, researching nanopositioning systems for applications including scanning probe microscopy, nanomachining and adaptive optics. LDCN collaborates internationally with the IBM Zurich Research Labs, the University of Stuttgart and the University of Glasgow.

The **University of South Australia's Centre for Advanced Manufacturing Research** is collaborating with the Hefei University of Technology, China, and the Department of Mechanical Engineering at the National Taiwan University to develop a nano/micro metrology instrument, the Nano-CMM, that provides resolution of 10 nm. The research and development for the instrument's DVD probe is being carried out in Australia.

The Nano-CMM will have a finished accuracy target of 3 nm. This new instrument will fill the measurement gap between the ATM/STM and TEM, and will allow measurements with a very high accuracy.

The Nano-CMM probe was developed using a singe optical assembly mechanism. The unique properties of this optical fibre detects fluctuation of the probe, producing higher precision measurements with applications for micro-electro-mechanical systems (MEMS) parts (such as micro groove, micro structures, film thickness, micro holes and channels, and wave guide) and lithography parts (such as gratings, micro lens, micro array and micro moulds).

The Centre is also developing facilities for DNA microarray technology in collaboration with the Department of Genetic Medicine at the Adelaide Women's and Children's Hospital. It has two major projects in development. The flexible microarray fabrication system project focuses on the development of an ink-jet style printer that can fabricate the microarray with the DNA sequence required for diagnosis and research purposes. The high-throughput hybridisation station project aims to develop a station with active micro-mixing and hybridisation progress monitoring features in order to shorten the hybridisation lead time and improve the quality of the hybridisation.

The **Centre for Computational Molecular Science (CCMS)** at the **University of Queensland** is an interdisciplinary research centre focusing on cutting-edge research in molecular scale modelling and the development of new molecular and computational methodologies. It has an international reputation in quantum simulation or quantum dynamics of chemical reactivity.

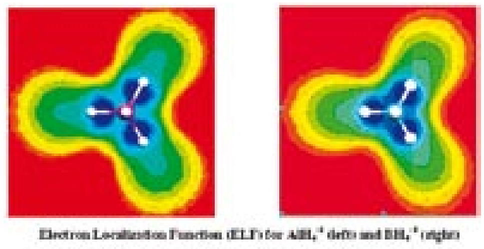
CCMS's current research projects include fluorescent proteins, hydrogen storage, quantum dynamics and complex kinetics, drug and gene delivery, and protease modelling using first-principle study of catalytic mechanisms. The Centre is developing many interdisciplinary projects in the areas of hydrogen storage materials and biomolecular proton transfer. These complex systems require hierarchical methods incorporating a combination of quantum chemistry, quantum dynamics, molecular dynamics and stochastic kinetic methods.

The Centre has developed a computational program to elucidate the interactions of atomic and molecular hydrogen with novel new nanomaterials designed for hydrogen storage applications. The calculations interact intimately with the experimental design process by enabling an understanding of the mechanistic features that drive the observed variations in storage properties for different combinations of materials.

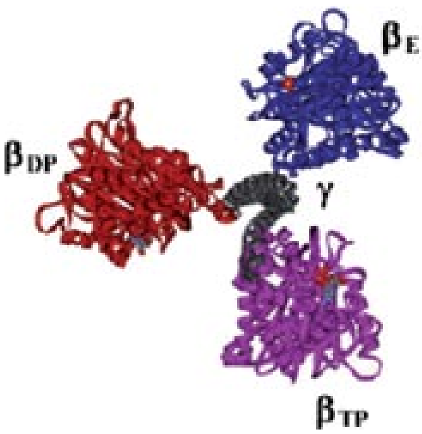
CCMS has also identified fluorescent proteins as an area of significance for in vivo imaging. The Centre has focused on green fluorescent proteins (GFPs) and their derivatives to develop a rational design program for a new class of red fluorescent proteins (RFPs) that have potential medical diagnostic applications.

The **Centre for Molecular Simulation (CMS)** at **Swinburne University of Technology** provides a focus for research in molecular simulation, obtaining fundamental insights into natural phenomena at the atomic level. CMS implements and develops computational techniques such as Monte Carlo, equilibrium molecular dynamics and non-equilibrium molecular dynamics to explore a wide range of phenomena such as phase equilibria, transport phenomena and nanotechnology. CMS is focusing on using molecular simulation and other computational techniques to gain theoretical insights into how nanosystems work. It is currently researching the operating mechanisms and dynamics of a particular type of biomolecular rotary motor, adenosine triphosphate synthase. This biological molecule acts as a proton pump by pumping hydrogen ions between different parts of a cell to moderate intracellular pH levels, and as a source of molecular propulsion. Another focus is on dendrimers, which are a new class of molecules that are likely to feature prominently in nanofabrication and new ways of bio-drug delivery. CMS also performs theoretical and simulation studies of the transport of molecular fluids in highly confined (nanometre) channels.

The **University of Western Australia's Centre for Strategic Nano Fabrication** is working with Clarkson University in the US on a project that uses rotating surface technology to fabricate nanoparticles. This includes spinning disc processing (SDP) (or spinning disc reactor technology), which represents a paradigm shift in engineering for application in the chemical transformation of molecules and the formation of mono-dispersed nanoparticles through a continuous flow technique.



Modelling image of Electron Localisation Function (ELF) for AH_4^{-1} (Left) and BH_4^{-1} (Right) anions, developed by the Centre for Computational Molecular Science (CCMS). Image courtesy of CCMS, University of Queensland



Schematic top view of the Ð protein domains of the F1F0-ATPase molecular motor. Image courtesy of The Centre for Molecular Simulation, Swinburne Universtity of Technology.

In SDP, the flow rate, concentration, speed of the disk and the change of surfactant set the parameters that control the size of nanoparticles to a very narrow size distribution. SDP can be used to prepare nanoparticles of inorganic materials, as well as organics and pharmaceuticals. This 'bottom-up' flash nanoparticle formation proceeds via transient super-saturated solutions formed through precipitation reactions or upon lowering the solubility of the substances by adding a second solvent to the molecular solution.

Solutions formed on the surface of the disc have short and controllable residence time with shorter induction time for nucleation and outgrowth of the particles. A key feature of SDP is the ability to control the size, size distribution, shape of particles and surface functionality in a single pass. This has exciting applications in nanotechnology, especially in addressing the important issue of toxicology at the inception of the nanoscience. The continuous flow of SDP facilitates scale up and avoids the use of batch technology, which often requires separate mixtures.

Cleveland Biosensors develops time-critical diagnostic testing instruments that can be used by non-technical operators to provide high performance in the field. The company has developed a hand-held biosensor capable of sensitive quantification of small organics, large proteins and pathogens. The BioFiniti® system comprises a fully autonomous hand-held electronic device that controls and reads disposable cartridges. The BioFiniti® Cartridge is smaller than a credit card yet stores, pumps, meters, mixes, purifies and washes reagents and samples, all with no moving parts. The BioFiniti® device provides a commercial alternative for point-of-care quantification of low concentration targets in difficult matrices by integrating complex microfluidic features and electronic sensing elements into a low-cost injection-moulded microfluidic device. Cleveland Biosensors is initially applying the technology to the sensitive sub-10-minute immuno-detection of peptides in dirty matrices and sub-one-hour quantisation of viable pathogens. Commercial opportunities encompass the use of the BioFiniti® system with third-party detection systems.

X-ray ultramicroscopy, originally developed by **CSIRO (Commonwealth Scientific and Industrial Research Organisation)**, and now commercialised by **XRT Pty Ltd**, has been used for nanoscale visualisation and measurements. The technique exploits X-ray phase contrast imaging to boost the quality and information content of images and provides greatly enhanced visibility of weakly absorbing and fine-scale features. This technique is capable of providing 2-dimensional (up to 50 nm resolution) and 3-dimensional (up to 500 nm resolution) images for non-destructive inspection and quantification of internal structures (for example, nanodispersion, fracture behaviour and bulk structure of biodegradable materials) of polymer nanocomposites and bioplastics.

Iatia Limited is a leading wavefront imaging company with visualisation and measurement applications in nanotechnology, the life sciences, ophthalmology and defence. Its unique Quantitative Phase ImagingTM (QPI™) technology, which was originally developed at the University of Melbourne, enables the real-time imaging of otherwise invisible objects by adding shape and form to an image. QPI™ uses traditional imaging technology, such as digital cameras (meaning no special optical components are required), to extract phase and wavefront information. In effect, QPI™ provides a digital phase contrast solution to transmission imaging techniques at the nanoscale where few other contrast mechanisms are available due to fabrication difficulties for short wavelength radiations like electrons and X-rays.

Iatia has formed partnerships with companies including the US-based Xradia, which develops high-efficiency zone plate lenses for X-ray imaging, and Intel, to develop other micro-focusing applications. GE Healthcare has incorporated Iatia's technology into one of its cell analyser products, while in 2004 the Japanese electron microscopy specialist HREM released a new product capable of photographing the atomic structure of the base material of silicon chips to provide magnetic field maps using Iatia's technology. Iatia is seeking partners to incorporate its technology in the nanotechnology, defence, ophthalmology and life sciences fields.

INPHAZE Pty Ltd specialises in scientific instruments. The company's first-generation scientific instrument is an impedance spectrometer that has an order of magnitude increase in precision over all commercially available impedance spectrometers. The INPHAZE spectrometer operates with a phase precision of one-thousandth of a degree (0.0010) and an impedance magnitude resolution of two-thousandth of a percent (0.002%). This allows the spectrometer to produce detailed information about the fine structure of materials down to the nanometre and Angstrom ranges. At this level of analytic detail, distinct layers of matter can be observed, including the arrangement of molecules and atoms. INPHAZE is seeking international technology licence partners to license the INPHAZE high-resolution impedance technology for manufacture and global distribution. The company is also interested in locating end users in major international research organisations.

MEMS-ID Pty Ltd is a radio frequency identification (RFID) company founded in 2003. The company is developing passive RFID tags with sensor capabilities that can be sterilised and irradiated. These RFID tags will use a novel method of programming and storing data on the device and will be able to be fabricated simply and inexpensively using the micro-electro-mechanical systems (MEMS) technology. The RFID tags are initially being applied to track medical instruments. There is currently no other RFID tag that can survive the instrument sterilisation process, including irradiation. The durability of the tags and their sensor capabilities enable a range of other applications in the healthcare, security and foodstuffs industries.

PicaMS Pty Ltd is a scientific consultancy that aims to enable the development of better materials and products for the manufacturing, engineering and resource industries. PicaMS provides industry access to cutting-edge instrumentation in research institutions. The company provides services in nanocharacterisation and physical modelling, which are used to diagnose product failure and for product development. To diagnose the causes of product failure and provide quality assurance, PicaMS uses electron beam techniques, such as scanning and transmission electron microscopy, to provide characterisation of materials structure ranging from 0.2 nm and upwards. The company uses a combination of electron beam characterisation, theoretical workup and physics-based problem solving for process and product development. Recent projects include analysing the spontaneous fracture of flat glass and remediation of glass facades with nickel sulphide contaminants, identifying applications of superconductivity and using scanning and transmission electron microscopy for the micro and nanocharacterisation of materials.

XRT Limited develops and manufactures X-ray systems optimised for high-resolution phase contrast imaging. Based on pioneering research conducted at CSIRO (Commonwealth Scientific and Industrial Research Organisation), XRT's X-ray technology offers non-destructive imaging of the internal structure of materials with micron and nanometre scale resolution. X-ray phase contrast provides the ability to image weakly absorbing samples such as low density composites, polymers and soft tissue – materials that give very poor contrast using conventional absorption based X-ray techniques.

In addition, X-ray phase contrast data generates edge enhancement not seen with absorption based X-ray imaging. The improved visualisation of edges heightens the spatial resolution and contrast of the image, thus increasing both the sensitivity and specificity of image data, which is very beneficial for industrial and medical imaging applications. XRT offers standard and custom-built products, as well as licensed use of its novel phase contrast imaging technology, which has international patents. XRT's products have been successfully implemented in prestigious institutions throughout the world. Its X-ray ultraMicroscope, for example, is in use at the Lawrence Livermore National Laboratory in the US. This system has a demonstrated resolution of sub 100 nm. The X-ray ultraMicroscope is now being sold under licence by California-based Gatan Inc., a member of the Roper Industries Group.

Facilities, Networks and Associations

Australia recognises that a multi-disciplinary skills base is essential to maintain its world-class nanoscience and nanotechnology. The country has research institutes, joint ventures, centres of excellence and research clusters that focus on applied research into nanotechnology applications across industries.

These facilities are closely linked and frequently collaborate on projects, enhancing interactions between researchers and providing avenues for bringing products to market. Australian networks and associations work to improve international links by supporting conferences, workshops, researcher training and tours by visiting lecturers.

Australia's international linkages ensure all participants in the Australian nanotechnology field are well connected and communicating, to assist technology diffusion across industries.

ANSTO at Lucas Heights, has for several years been working on Synroc, a synthetic substance that will be used to contain nuclear waste. Materials scientist, Sam Morrica with a smaller example of the compressed Synroc container and a cross section of same,

Free-standing porous inorganic membranes. Image courtesy of Australian Nuclear Science and Technology Organisation (ANSTO).

Established in 2007, the **Australian Microscopy and Microanalysis Research Facility (AMMRF)** is a joint venture between Australian university-based microscopy and microanalysis centres. The AMMRF is a national grid of equipment, instrumentation and expertise in microscopy, microanalysis, electron and X-ray diffraction and spectroscopy providing nanostructural characterisation capability and services to all areas of nanotechnology and biotechnology research.

The Facility operates in nodes in major capital cities (Adelaide, Brisbane, Canberra, Melbourne, Perth and Sydney) and has links to smaller units in specialist facilities. It provides access to a vast array of platforms including widely used optical, electron, X-ray and ion beam techniques and, importantly, state-of-the-art flagship platforms that form world-leading capabilities. These include pulsed laser local electrode atom probes, high throughput cryo electron tomography, high-resolution scanning electron microscopy (SEM) and spectroscopy, high-precision ion microprobe and ultra-high resolution tunnelling electron microscopy (TEM) platforms.

By combining new flagships with existing capabilities, the Facility offers a complete, modern suite of instruments available to all Australian publicly researchers on merit basis and a nominal fee schedule. Industry researchers can also use the Facility for proprietary research at commercial rates.

Operational since mid-2006, the **Australian Nano Business Forum (ANBF)** which is Australia's peak national body, with members in all states, represents and promotes Australian industries and companies involved in nanotechnology. The ANBF provides a collective voice for member organisations engaged in this emerging technology, as well as facilitating links between other key stakeholders such as government, funding, regulatory and research entities. The ANBF has a truly national perspective and is not dominated by any state, industry or government. It is governed by a Board of Directors, with the Constitution allowing for each state to be represented.

The role of the ANBF is evolving and diverse. It includes representing and promoting Australian nanotechnology, both domestically and internationally; providing a mechanism for industry development incorporating nanotechnology companies and their key stakeholders; presenting a collective industry view to Commonwealth and State governments, regulatory, funding and other decision-makers; formulating linkages between industry and research communities to facilitate industry uptake of nanotechnology; and building confidence in nanotechnology in the investor community.

The **Australian Nanotechnology Alliance (ANA)** is an industry alliance with members comprising organisations that underpin Australia's current and future economic growth. Diverse industries represented include mining, manufacturing, agriculture, construction, biotechnology, marine, aviation and microelectronics.

ANA encourages collaboration between the three key stakeholder groups in the Australian nanotechnology environment – researchers, developers and manufacturers – representing the triple-helix strategies. This unique model focuses on increasing the awareness of nanotechnology to both initiated and uninitiated organisations, leading to the promotion of regional innovation, economic development and employment.

To assist ANA in working with public decision-makers on the development of policy and regulatory frameworks, four sub-committees actively gather information. Sub-committees examine infrastructure, business, regulation and workforce/skills. ANA communicates to members via its monthly newsletter NanoVate and through regular networking events that examine the diversity of areas where nanotechnology has an impact.

The **Department of Applied Mathematics** at the **Australian National University** hosts the Scanned Probe Microscope facility. The facility has three atomic force microscopes (AFM), two of which have been modified in-house to provide additional measurement facilities. The AFM technique is able to image non-conducting surfaces with sub-nanometre resolution in fluids. A range of contrast mechanisms are available such that images can reveal the topography, stiffness or interaction forces mapped in two dimensions. Surface forces normal to surfaces can also be studied on a wide range of surfaces and under a range of solution conditions.

The **Australian Nuclear Science and Technology Organisation (ANSTO)** applies its expertise in nuclear science and technology to the field of nanotechnology by undertaking discovery research and collaborating with universities, industry partners and research organisations. ANSTO's new research reactor OPAL and its suite of characterisation tools provide Australian researchers and industry with nanotechnology research tools comparable to those available in Europe, the US and Asia. The use of neutron diffraction, scattering and reflectometry techniques, along with complementary x-ray facilities, allows researchers to probe the evolution of nanostructured systems.

ANSTO's discovery science is also developing a comprehensive nanotechnology platform to produce and investigate engineered nanostructures. This is based on synthesis via sol-gel chemistry to produce functional nanoparticles, porous inorganic solids and organic/inorganic hybrid thin-films. Using complementary chemistry in the vapour phase, atomic layers and interfaces are able to grow uniformly on planar and porous structures. Materials of interest include single and multiphase oxide-based ceramics on polymers and bio-templates, engineered organic/inorganic hybrids and bio-inorganic encapsulated matrices.

End uses of ANSTO's nanotechnology research include radioisotope separation for radiopharmaceuticals and waste processing, energy production using lithium batteries and water splitting and other spin-off technologies such as protective barrier coatings, adaptive response coatings, surface modification/functionalisation, encapsulation and controlled release.

The OPAL research reactor and the National Medical Cyclotron create short-lived radioisotopes, which are essential parts of radiopharmaceuticals used as diagnostic tools in medicine. They can indicate blood flow, detect malfunctions in metabolism, and are being used to diagnose heart conditions, neuro-degenerative and thyroid diseases and cancer.

The **Australian Research Council Nanotechnology Network (ARCNN)** is a research network that aims to bring together people working in the field of nanoscience and nanotechnology. The network has more than 700 members with 150 research groups working on various aspects of nanotechnology. Its purpose is to enhance interaction among nanotechnology researchers in Australia and to improve international links by supporting conferences, workshops, summer schools, student and early career researcher training, distinguished lecturer tours and other outreach projects relating to nanotechnology development in Australia.

The **Australian Synchrotron** will significantly enhance Australia's capability in nanotechnology when it opens in mid-2007. The 3 GeV Australian Synchrotron will support a range of high-tech

The Australian Synchrotron. Image courtesy of Australian Synchrotron Project Department of Innovation, Industry and Regional Development

research and development, including micro-manufacture. Synchrotron light can be used to elucidate the structure and chemistry of samples and in the manufacture of high aspect ratio devices by lithography.

Forged through a unique partnership between the states, universities and Australian and New Zealand research organisations, the Australian Synchrotron will be available to all researchers and collaborators. The Facility has strong links with major international synchrotron facilities, including the Advanced Photon Source in the US, the European Synchrotron Light Source in France, the Swiss Light Source, the recently opened Diamond Light Source in the UK and Spring-8 and the Photon Factory in Japan. In addition, the Australian Synchrotron Research Program (ASRP) provides Australian researchers with access to several international synchrotron light source facilities.

AZoNano was founded in 2003 and is a comprehensive international online resource dedicated to informing and educating engineers, designers, academics and scientists from within the global nanotechnology community, from materials and equipment through to research and new developments. AZoNano contains over 6,000 regularly updated pages of technical data, application-based information, feature articles, company profiles and expert listing from individuals, institutions and companies from around the world.

Catapult Innovations Pty Ltd is a product-realisation consulting company specialising in nano, micro and biotechnologies. Rather than performing its own fundamental nanotechnology research, Catapult works with innovators in the field to turn their technology into complete product offerings. Instead of rough proof-of-concept prototypes, clients are able to present fully integrated product solutions to investors or customers. Catapult Innovations supplies a full range of engineering expertise (mechanical, software, firmware, electronics, industrial design and project management), as well as market research and product definition methodologies specific to disruptive technologies. The team has its origins in the Australian CRC for MicroTechnology, giving it five years experience and a proven track record in integrating small-scale technology innovations into products.

The **Centre for Materials and Surface Science** at **La Trobe University** is an interdisciplinary research group with interests in the development of advanced composite materials incorporating carbon nanotubes; investigation of metal forming and the role of lubricants; application of functional coatings on industrial polymers; molecular interactions at surfaces; surface modification and ageing of polymers; synchrotron-based characterisation of materials using electronic, compositional and structural techniques and the development of unique instrumentation; creation and interrogation of novel X-ray optical structures using micro- and nanofabrication and synchrotron techniques; semiconductor growth by molecular beam epitaxy; fabrication of micro-patterned biodiagnostic structures using soft lithography and electrochemical techniques; surface science of paper; characterisation of protein uptake on resins; surface chemistry of bacteria and immobilised DNA; and environmental surface chemistry including remediation and ion transport issues.

The Centre collaborates with or provides analytical services to 15 Australian and international universities, three divisions of CSIRO (Commonwealth Scientific and Industrial Research Organisation), the Defence Science and Technology Organisation (DSTO) and around 30 Australian and international companies. It has key roles in and partnerships with the Australian Research Council Centre of Excellence in Coherent X-ray Science, the Victorian Centre for Advanced Materials Manufacturing, the BESSY Synchrotron in Germany and the Australian Synchrotron.

The Centre has extensive, world-class characterisation infrastructure, including X-ray photoelectron spectroscopy (XPS), time-of-flight secondary ion mass spectrometry (TOF-SIMS), photoelectron spectroscopies, X-ray micro-tomography, optical contact angle analysis, scanning probe microscopy, optical microscopies and a variety of synchrotron-based resources.

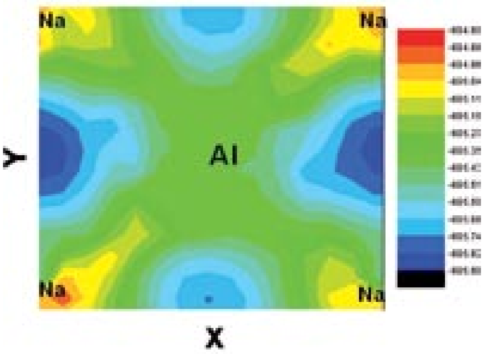
The **High Resolution Synchronised Differential Scanning Calorimetry-Thermogravimetry-Infrared Spectroscopic (DSC-TGA-FTIR) Facility** at the **University of Western Sydney (UWS)** conducts thermodynamic, kinetic and spectroscopic analyses of high temperature processes simultaneously. The state-of-the-art Facility features a simultaneous differential scanning calorimetry thermogravimetric analysis (DSC-TGA) component (NETZSCH, Jupiter 449C) Rhodium furnace operating from ambient to 1,650°C. The thermo-balance has exceptional resolution (10^{-7} g), which is 1,000 higher than that of a typical analytical balance. The DSC-TGA component is hyphenated to the Fourier-transform infrared (FT-IR) spectrometer (Bruker, VERTEX 70) via interface with constantly heated at 200°C transfer line and fast and highly sensitive liquid nitrogen cooled MCT detector (7,000–600 cm^{-1} wavenumber interval).

The Facility's researchers have established collaborations with the Department of Amorphous Materials, Institute of Physical Chemistry at the Bulgarian Academy of Sciences. The typical applications for the DSC component include specific heat capacity, melting and crystallisation temperatures, transition enthalpies (heat of melting and crystallisation, ΔH), heat of reaction, phase transformations, phase diagrams, crystallisation temperatures, degree of crystallinity, glass transition temperatures, decomposition effects, reaction kinetics, oxidative stability, thermal stability and purity determination.

The TGA component has applications for mass changes, decomposition temperatures, dm/dt = rate of mass change/decomposition, dehydroxilation, corrosion/oxidation, thermal stability, reduction studies, composition, reaction kinetics and purity determination. Applications using the simultaneous system include out-gassing of materials, detection of residuals, analysis of additives, aging and decomposition processes (oxidation, pyrolysis), characterisation of natural and raw materials, desorption behaviour and extension of chemical reactions (catalysis, synthesis, polymerisation).

In addition to a pre-existing spectrometer, the new **Biomedical Magnetic Resonance Facility** at the university houses two new nuclear magnetic resonance (NMR) spectrometers: a Bruker Avance 500 MHz widebore NMR spectrometer for very high resolution NMR imaging and NMR diffusion measurements; and a Bruker Avance 400 MHz NMR spectrometer for diffusion measurements in low viscosity liquids and normal spectral identification of molecules. This Facility is arguably the best of its kind in Australia, and perhaps the Southern Hemisphere, for experiments of this kind.

The **Ian Wark Research Institute (The Wark™)** at the **University of South Australia** is the **Australian Research Council (ARC) Special Research Centre for Particle and Material Interfaces**. It is also the headquarters of the Australian Mineral Science Research Institute (AMSRI), a virtual institute embracing outstanding research teams at the University of South Australia, the University of Melbourne, the University of Newcastle and the University of Queensland. The Wark™ provides consulting, testing and analytical services, primarily involving surface analysis of metals, minerals, polymer, glass, adhesives, paints and pharmaceuticals. It also provides



Modelling image of PES-Ti on NaAlH4 developed by The Centre for Computational Molecular Science (CCMS). Image courtesy of CCMS, University of Queensland.

environmental and component failure analysis. Interaction between The Wark™ and industry is very strong – the Institute provides research and development, consulting and testing, and other professional services and advice. The Scientific Services division has considerable experience in both academic and industrial environments.

Fabrication facilities established in the **Department of Physics** at **Macquarie University** include ultraviolet-visible (UV-VIS), nanosecond and sub-picosecond laser micromachining of metals, polymers, glasses, ceramics and crystalline materials and related laser processing, such as laser and photonic surface modification and cleaning of contaminants including particles. Associated capabilities include micropositioning for device integration and related test and diagnostic instrumentation.

The **Optical Characterisation Facility** offers state-of-the-art research infrastructure in microspectroscopy and diagnostics, including: a micro Raman spectroscopy system (Renishaw 1000B), which operates in the UV (325, 406, 442 nm) and is uniquely suited to operate by surface enhanced Raman scattering (SERS); near field optical microscopy/atomic force microscopy (NSOM/AFM, Nanonics NSOM/SPM-100 Confocal Microscopy), which is designed to detect and map electromagnetic fields in the close proximity of an illuminated object (within nanometres) and is uniquely designed to be used concurrently with the Renishaw Raman system; combined fluorescence spectroscopy/micro fluorescence spectroscopy/ fluorescence lifetime (Fluorolog Tau-3 based system), which provides a unique fluorescence excitation and lifetime system combined with mapping; and Leica TCS SP and SP2 multifunctional laser scanning microscopes with multiphoton and lifetime imaging capabilities (two microscope systems).

Macquarie University also has a Veeco Optical Surface Profiler that operates in two different modes: phase-shifting interferometry (PSI) mode with a vertical resolution of 0.1 nm, which is used for very smooth surfaces with surface roughness less than 160 nm; and vertical-scanning interferometry (VSI) with a vertical resolution of 1 nm. Vertical scans can be up to 1 nm in VSI mode. The user can view surface topology in 3-dimensions and in cross sections, measure dimensions of features on the surface and make surface roughness measurements.

The University is looking to build a world-unique infrastructure facility to make its platform technology in UV/VUV plasma sources available to the Australian research and technology community.

The University also hosts the Australian Research Council/National Health and Medical Research Council (ARC/NHMRC) research network Fluorescence Applications in Biotechnology and Life Sciences (FABLS). Members come from research institutions throughout Australia, a number of overseas universities and private companies in Australia and overseas. FABLS unites those members who have an interest, expertise and capabilities related to fluorescence applications in biotechnology and life sciences. It aims, through applications of these technologies within Australia, to foster benefits such as improved public health diagnostics, improved processing and quality of foods and beverages, development of new technology-based companies and increased use of research infrastructure.

MiniFAB creates advanced products through the implementation of unique scientific, engineering and manufacturing know-how. The company designs, integrates and manufactures polymer micro and nano-engineered systems for the biotech, health, agriculture and food industries. MiniFAB works with clients to develop product strategies, create manufacturing methods, provide pilot and batch scale manufacturing meeting regulatory compliance testing, and create volume manufacturing operations.

MiniFAB's approach to technology allows for simplified manufacture of products using batch processing, photolithographic techniques, and minimal types of materials and numbers of components. This approach leads to reduced manufacturing costs, increased product reliability and the development of low-cost disposable devices. MiniFAB uses high throughput manufacturing strategies, matched with rapid turn-around development tools, enabling the company to demonstrate solutions quickly.

MiniFAB's nanotechnology expertise lies in packaging nanotechnologies into applications, such as applying nanofilms to a micro-fluidic chip and then incorporating it into a complete system for applications such as diagnostics. It has also implemented nano-imprint lithography for the fabrication of nanoscaled structures. The company has developed numerous devices and components, including micro-chemical reactors, biosensor cartridges, bio-fluidic handling systems and connectors, and integrated active components such as valves, pumps and optical elements.

A high-profile example of MiniFAB's nanotechnology work is its involvement in the SmartHEALTH Integrated Project (IST-NMP-2-016817), which is part of the European Union's Sixth Framework Programme and aims to develop the next generation of intelligent medical diagnostic platforms. MiniFab is the only non-European member of this project and is developing a manufacturing packaging strategy for nanotechnology-based biosensors for biological species detection.

The **Monash Centre for Synchrotron Science** is a cross-faculty centre at **Monash University** that focuses on synchrotron science. It was established to capitalise on opportunities offered by the Australian Synchrotron being built adjacent to the university's Clayton campus.

The Centre facilitates and coordinates synchrotron research across Monash University and has research staff in a number of academic departments, as well as a staffed central office. The Centre supports technical staff who are developing platform technologies for synchrotron and allied use. For example, its instrumentation group is developing detector and optics technologies to support researchers to achieve the best results from their synchrotron experiments, especially those related to biomedical imaging.

Nanotechnology Victoria (NanoVic) was formed as a consortium dedicated to the industrial exploration of nanotechnology. Founding members include Monash University, RMIT University, Swinburne University and CSIRO (Commonwealth Scientific and Industrial Research Organisation). NanoVic also works with a variety of other research providers across Australia. NanoVic has conducted more than 60 projects in the last three years, and established relationships with many of Australia's leading technology-based corporations.

NanoVic has played a leading role in the development of Australia's National Nanotechnology Strategy. It has also been a key player in the formation of the Australian Nano Business Forum (ANBF). NanoVic is researching toxicology assessment and helped establish NanoSafe Australia, a network of toxicologists focused on nanoparticle occupational health and safety issues. NanoVic, led by Monash University, has also contributed to the development of regulatory perspectives and to a considerable range of nanotechnology educational and public awareness materials.

The **National Measurement Institute (NMI)** provides world-class measurement standards and services to industry, government and the community in physics, chemistry and biology. It is widely regarded to be among the top 10 measurement institutes in the world. Its international credibility is demonstrated through participation in the Mutual Recognition Arrangement (MRA) of the International Committee for Weights and Measures (CIPM).

Countries that are signatories to the CIPM MRA recognise the equivalence of each other's measurement standards and the capabilities of their national measurement bodies. For industry, this means that measurement standards traceable to NMI are recognised internationally as equivalent to those of organisations such as the US National Institute of Standards and Technology (NIST) and similar national bodies.

NMI's expertise in developing and maintaining measurement standards at high levels of accuracy is available to support industry in calibrating measuring instruments and resolving measurement-related problems. NMI has high-level measurement expertise in chemistry and biology and develops chemical reference materials and methods for industry. This expertise can help solve measurement problems in nanotechnology, which is expected to have powerful applications in chemistry and biology.

NMI's nanometrology laboratory draws on the Institute's broad metrological expertise. It supports industry by providing practical assistance with nanoparticle measurements. NMI is developing measurement standards for nanoparticles to underpin this service.

The **Small Technology Cluster (STC)** is creating a world-recognised centre of excellence through the clustering of accessible skills, technologies and capabilities in micro/nano/biotechnology research, manufacturing and commercialisation. The STC offers state-of-the-art equipment and a highly trained workforce in a clustered and highly interactive environment. The STC aims to be Australia's foremost generator of business and innovative manufacturing activity based on the exploitation of small-scale technologies.

Central to the STC is the 50,000 sq ft MiniFAB facility, which offers customised manufacturing and advanced product development in micro-engineered systems for biotech, health, agriculture and aerospace. The STC also has access to a 4,000 sq ft good manufacturing processes (GMP) facility.

Beyond its own cluster capabilities, the STC provides access to a vast network of Australian and international researchers, developers, capabilities and facilities. The STC is working with national and international businesses interested in innovation partnering in this unique environment.

Swinburne Knowledge facilitates, supports and monitors Swinburne University's commercialisation activities. This extends to the provision of advice and expertise to senior managers and unit managers operating or planning commercial activities.

Swinburne Knowledge has systems to identify and evaluate the commercial potential of emerging opportunities, to assess applications for seed funding for new ventures and to allocate funding. The latter function draws on a significant level of outside commercial expertise. The primary vehicles for commercialisation of university intellectual property are establishing spin-off companies, licensing and contracting various commercial activities.

Australian Nanotechnology Matrix

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
Acme Nano Products Pty Ltd	■						
Advanced Nanotechnology Ltd	■						
AorTech Biomaterials Pty Ltd		■					
ARC Centre of Excellence for Antimatter-Matter Studies				■			
ARC Centre of Excellence for Complex Dynamic Systems and Control						■	
ARC Centre of Excellence for Coherent X-ray Science				■			
ARC Centre of Excellence for Electromaterials Science		■					
ARC Centre of Excellence for Functional Nanomaterials	■	■	■				
ARC Centre of Excellence for Photovoltaics				■			
ARC Centre of Excellence for Quantum-Atom Optics					■		
ARC Centre of Excellence for Quantum Computer Technology					■		
ARC Nanotechnology Network							■
ARC Special Research Centre for Particle and Material Interfaces	■	■	■				■
Artimech Pty Ltd						■	
Asia Nanomaterials Pty Ltd	■						
Astute Nanotechnology		■	■				
Australian Institute for Bioengineering and Nanotechnology		■					
Australian Membrane Technologies		■					
Australian Microscopy and Microanalysis Research Facility							■
Australian Nano Business Forum							■
Australian Nanotechnology Alliance							■
Australian National University Atomic and Molecular Physics Laboratry				■			
Australian National University Browitt Nanoparticle Laboratory		■					
Australian National University Centre for Sustainable Energy Systems			■				
Australian National University Department of Applied Mathematics	■						■
Australian National University Electronic Materials Engineering	■			■			
Australian National University Laser Physics Centre					■		
Australian National University Research School of Chemistry	■	■	■				

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
Australian National University Research School of Physical Sciences and Engineering				X			
Australian Nuclear Science and Technology Organisation (ANSTO)		X		X			X
Australian National University Space Plasma and Plasma Procession Program				X			
Australian National University Space Plasma, Power and Propulsion			X				
Australian Synchrotron							X
AZoNano							X
Bandwidth Foundry				X			
Bio21 Molecular Science and Biotechnology Institute		X					
Biochip Innovations		X					
BioLayer Pty Ltd		X					
Biopharmica Ltd		X					
BioSenZ Pty Ltd		X					
Bluglass Ltd	X						
CAP-XX Pty Ltd			X				
Catapult Innovations							X
Centre for Green Chemistry		X					
Centre for Nanotechnology and Biomaterials		X					
Centre for Ultrahigh bandwidth Devices and Optical Systems				X			
Ceramic Fuel Cells Ltd			X				
CeramiSphere Pty Ltd		X					
Cleveland Biosensors						X	
Cochlear Ltd		X					
Cooperative Research Centre for Advanced Composite Structures	X						
Cooperative Research Centre for Coal in Sustainable Development			X				
Cooperative Research Centre for Contamination Assessment and Remediation of the Environment			X				
Cooperative Research Centre for Environmental Biotechnology		X					
Cooperative Research Centre for Functional Communication Surfaces	X						
Cooperative Research Centre for National Plant Biosecurity		X					

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
Cooperative Research Centre for Oral Health Science		X					
Cooperative Research Centre for Polymers	X	X	X				
Cooperative Research Centre Smartprint	X						
CRC CARE Pty Ltd			X				
CSIRO (Commonwealth Scientific and Industrial Research Organisation)	X	X	X	X	X	X	
Defence Science and Technology Organisation (DSTO)				X			
Dyesol Limited			X				
Edith Cowan University Western Australian Centre of Excellence for MicroPhotonic Systems				X			
Flinders University	X		X				
Flinders University BioNanotechnology Laboratory		X					
Flinders University Nanomaterials Group	X						
Flinders University Nanostructures and Molecular Interactions Research Group		X					
Flinders University Smart Surface Structure Group	X						
G.James Australia	X						
Griffith University Nanoscale Science and Technology Centre	X			X			
Hydrexia Pty Ltd			X				
Ian Wark Research Institute	X	X	X				X
Iatia Limited				X		X	
iCeutica		X					
i-Glass Projects Pty Ltd				X			
INPHAZE Pty Ltd						X	
KingGee	X						
La Trobe University Centre for Materials and Surface Science	X						X
La Trobe University Centre for Technology Infusion				X			
Lu Papi and Associates	X						
Macquarie University Nanobiophotonics Research Group		X					
Macquarie University Centre for Lasers and Applications		X		X			
Macquarie University Department of Physics	X			X			X

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
Macquarie University Optical Characterisation Facility							■
Macquarie University Short Wavelength and Interactions with Materials Group			■	■			
Melbourne Ventures		■					
MEMS-ID						■	
Micronisers Pty Ltd	■						
MiniFAB		■					■
MiyoTech Limited				■			
Monash University Centre for Synchrotron Science							■
Monash Institute for Nanosciences		■	■				
Murdoch University Murdoch Applied Nanoscience Research Group		■	■				
Murdoch University Murdoch Energy Science Group			■				
NanoChem Holdings Pty Ltd			■				
Nanomics Biosystems		■					
NanoQuest Pty Ltd			■				
Nanosonics Ltd		■					
Nanotec Pty Ltd	■						
Nanotechnology Victoria	■	■	■				■
National Measurement Institute							■
Novel Laser Technologies	■						
Orica Ltd	■						
Pepfactants Pty Ltd	■						
PicaMS Pty Ltd						■	
Plantic Technologies			■				
Poly Optics Pty Ltd				■			
PolyNovo Biomaterials Pty Ltd		■					
Prima BioMed Ltd		■					
pSivida Limited		■					
Quantum Communications Victoria				■			
Qucor Pty Ltd					■		

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
Queensland University of Technology	■	■	■	■			
Resilin, CSIRO		■					
Rio Tinto	■						
RMIT Integrated Optics Research Group				■			
RMIT Microelectronics and Materials Technology Centre	■			■			
RMIT Rheology and Material Processing Centre	■						
RMIT School of Applied Sciences	■		■				
RPO Pty Ltd	■						
Seagull Technologies		■					
Silicon Sands Pty Ltd	■						
Sirtex Medical Ltd		■					
Small Technology Cluster							■
Starpharma Holdings Ltd		■					
Sustainable Technologies International Pty Ltd			■				
Swinburne Knowledge							■
Swinburne University of Technology Centre for Micro-Photonics				■			
Swinburne University of Technology Centre for Molecular Simulation						■	
TAG Technology	■						
UniQuest Pty Ltd	■	■	■				
University of Adelaide Centre for Biomedical Engineering		■					
University of Adelaide Centre of Expertise in Photonics				■			
University of Adelaide School of Chemistry and Physics		■		■			
University of Adelaide T-ray Group				■			
University of Melbourne Centre for Nanoscience and Nanotechnology		■			■		
University of Melbourne Department of Chemical and Biomolecular Engineering		■					
University of Melbourne Microanalytical Research Centre				■			
University of New South Wales School of Physics				■			
University of New South Wales Centre for Advanced Macromolecular Design		■					
University of New South Wales Laboratory for Nanoscale Interfacial Design Group		■					

Name of company/institute	Materials	Nano-biotech & Medical Devices	Energy & Environment	Electronics & Photonics	Quantum Technology	Instrumentation & Software	Facilities, Networks & Associations
University of New South Wales Quantum Electronic Devices Group					■		
University of New South Wales School of Chemistry		■					
University of New South Wales School of Material Science and Engineering	■						
University of Newcastle Centre for Organic Electronics				■			
University of Newcastle Surface and Nanoscience Group	■						
University of Queensland Centre for Computational Molecular Science						■	
University of South Australia Centre for Advanced Manufacturing Research	■					■	
University of Technology, Sydney			■	■			
University of Technology, Sydney Department of Physics and Advanced Materials	■						
University of Technology, Sydney Cell and Nanobiotechnology Research Group		■					
University of Technology, Sydney Institute for Nanoscale Technology	■						
University of Western Australia Centre for Atomic, Molecular and Surface Physics				■			
University of Western Australia Centre for Strategic Nano-Fabrication	■					■	
University of Western Australia School of Electrical, Electronic and Computer Engineering				■			
University of Western Sydney Biomedical Magnetic Resonance							■
University of Western Sydney High Resolution Synchronised Differential Scanning Calorimetry-Thermogravimetry-Infrared Spectroscopic facility							■
University of Western Sydney Nanoscale Organisation and Dynamics Group	■	■					
University of Wollongong Intelligent Polymer Research Institute	■						
Very Small Particle Company Pty Ltd	■						
Viva Blu Pty Ltd			■				
Wriota				■			
XeroCoat Pty Ltd	■						
XRT Limited						■	

Index

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Starch is extracted from wheat and converted into plastic pellets that can be used as the base polymer material to make biodegradable packaging and other thermoformable objects.
CSIRO has developed a variety of biodegradable polymer materials from renewable resources such as starch, cellulose and protein. Nanoparticles and other additives can be applied to enhance the properties of these materials for specialised use in transport, packaging and medical applications. The technologies of starch-based biodegradable materials developed by CSIRO have received worldwide recognition and won various awards. Some of the technologies developed have been commercialised through the establishment of a spin-off company, Plantic.

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