ANFF

PROVIDING SOLUTIONS...

A CASEBOOK

Australian National Fabrication Facility

WELCOME

Rosie Hicks,
Chief Executive Officer
Australian National Fabrication Facility

Health, energy and sustainability are among the key societal challenges facing Australia and increasingly the solutions are being found at the nanoscale. From research into creating new techniques for drug delivery to designing devices for energy storage and capture, Australia's researchers must be able to build structures at the micro and nano scale. Nanofabrication is essential for converting scientific concepts into prototypes and commercial products.

In 2007, the Australian National Fabrication Facility began as a growing portfolio of fabrication facilities that were made available to all Australian researchers.

ANFF staff have turned these facilities into a world-class capability. They have trained communities of academics in state-of-the-art fabrication processes. They have worked with entrepreneurs to build prototypes of innovative products. They have collaborated with industry clients to develop new manufacturing processes using the latest science.

Most significantly ANFF has grown into an integrated network. It can now draw from a community of over 100 of Australia's top academic and technical staff across eight nodes to identify the best expertise and capability to address each fabrication problem.

Outcomes have included fundamental research published in high-impact journals; collaborative research with industries including automotive, food, and defence; and translational research such as development of the Nanopatch™.

In 2012, ANFF is no longer just providing facilities. It is now ***providing solutions*** for over 1,600 researchers.

It is with great pride that we present the casebook of solutions that ANFF has provided for Australian researchers.

CONTENTS

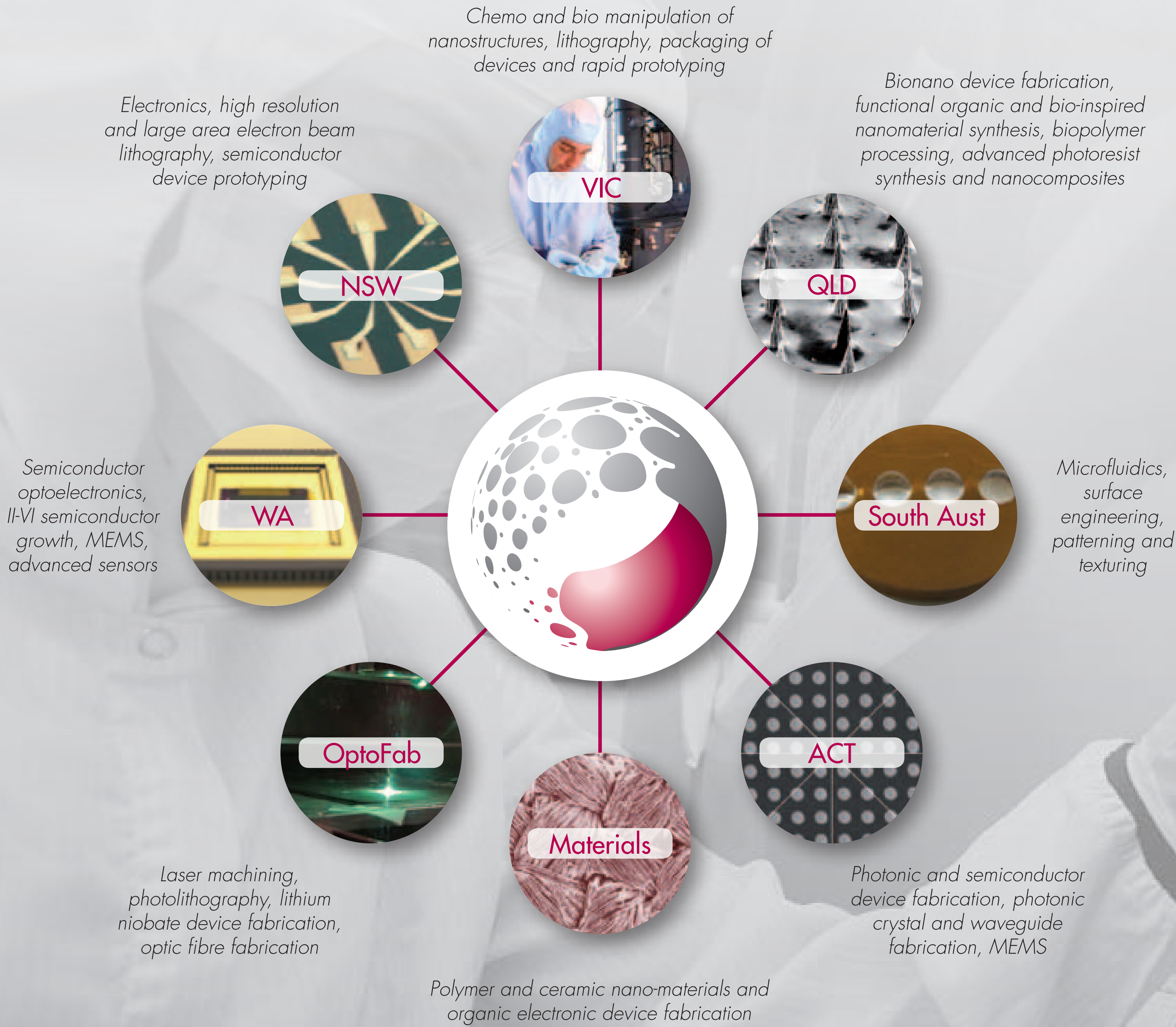
COVER IMAGE:
"3D printing steel using laser sintering"
Credit: Materials node, University of Wollongong.

SNAPSHOT OF ANFF

Established in 2007 under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS), ANFF joins 21 institutions to form a national network of 8 nodes. Each node offers facilities and a critical mass of knowledge in their specialist fields.

OUR MISSION

To provide micro and nano fabrication facilities for Australia's researchers.



OUR ACHIEVEMENTS 2011-12

Providing fabrication facilities for Australia's researchers

ANFF now provides a portfolio of approximately 500 facilities to all Australian researchers. It is comprised of infrastructure valued at almost $200 m. Over 1,600 clients benefited from the ANFF in 2011-12 with annual usage increasing 66%. In addition, over 1,800 orders of devices, materials or services were provided to our clients.

Training Australian researchers

Over 1,700 researchers were trained by ANFF technical staff. 980 of these were through the 131 courses held by ANFF nodes. 720 were one-on-one with ANFF technical staff providing specialist advice for their specific research problem.

Building a national network

44% of ANFF users travelled for facilities and expertise outside of their host university, taking advantage of ANFF as a truly national facility.

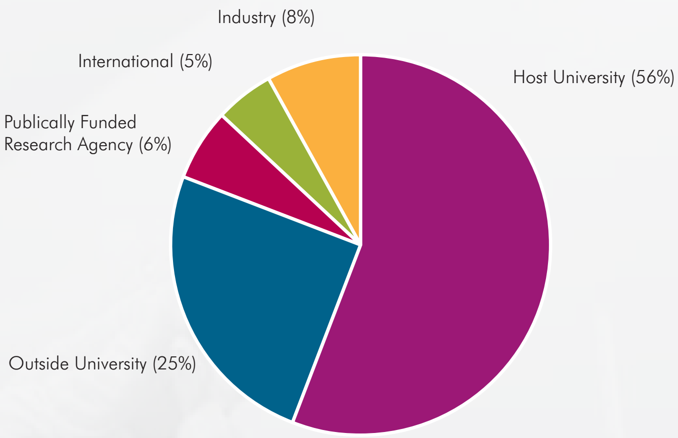
Inspiring collaboration

In 2011, 82% of ANFF supported publications in high impact journals were generated by collaborative projects.

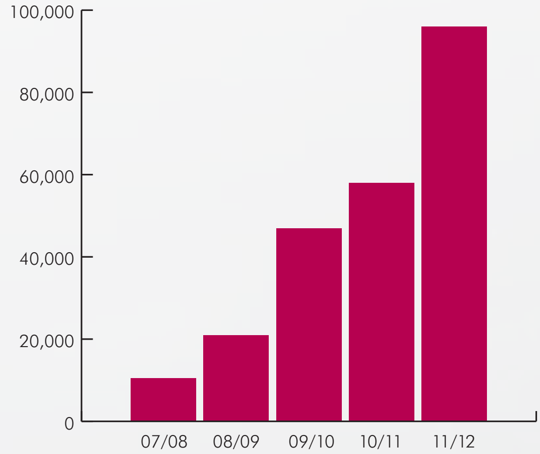
Inspiring economic development

Approximately 200 entrepreneurial and industrial clients used ANFF for commercial prototyping, hosting R&D operations or contract research. A number of these have won national innovation awards, and many are based entirely in ANFF laboratories.

ANFF USERS



FACILITY USAGE (hours)



On behalf of all of our users who make the ANFF network, we are proud to present this case book of success stories demonstrating how ANFF is providing solutions.

ANFF Showcase 2011. Credit: Warren McKenzie

FRONTIER TECHNOLOGIES

With Australia's best scientists in the network, ANFF is uniquely positioned to develop the latest cutting-edge science into frontier technologies. Such technologies are the seeds that Australian entrepreneurs can turn into a national competitive advantage.

Artist's impression of a single atom quantum bit - a phosphorus atom (red sphere surrounded by electron cloud, with arrow showing the spin direction) coupled to a silicon single-electron transistor. A burst of microwaves (blue) is used to 'write' information on the electron spin. Credit: Tony Melov

ANFF AND SMEs

Nanotechnology is increasingly becoming a pervasive and transformative force with impact on the manufacturing, health, environmental, security and service industries. For Australia to participate in the market it must undertake cutting-edge R&D and be able to translate this R&D into prototypes that form the basis of new industries.

Vaxxas:

Vaxxas is the result of a recent research project that has been transformed into a start-up company, with the help of ANFF.

Research efforts headed by University of Queensland Prof. Mark Kendall at ANFF-Q (the Queensland node) have developed a viable alternative to needle injections of vaccines; the Nanopatch. The Nanopatch advantages include: improved immune responses – achieved by targeting the skin's immune cells; and removing the need for vaccine refrigeration – because the vaccine is dry-coated to the Nanopatch projections. Collectively, the benefits could lead to Nanopatches sent in the post to people for self-administration.

The deep reactive ion etcher, photoplotter, hot embosser, cleanrooms, and support from local ANFF staff have all been key elements in the research phase developing the Nanopatch, and in helping advance its production processes such that it can be manufactured on a large scale.

Following a $15 million investment led by One Ventures, startup company Vaxxas will continue to use ANFF facilities for its pilot-scale production. This has potentially saved Vaxxas several million dollars it would otherwise have had to spend on similar equipment at this early stage of the company's development.

Phoenix Engineering Systems:

ANFF is supporting Phoenix Engineering Systems in its development of a nanoparticle hydrophone.

Funded via the highly competitive Defence Capability and Technology Demonstrator (CTD) Program, this project aims to deliver significantly improved underwater sonar sensing capabilities.

John Wilson, General Manager of Phoenix Engineering Systems describes the benefits of having ANFF on board:

"When contemplating submitting a proposal for the CTD, Phoenix planned to construct an in-house laboratory to conduct the necessary research on nano-particles for the Nano-Particle Hydrophone. However, our discovery of the ANFF, the staff's expertise in the field and the extensive facilities available at the various sites has enabled us to conduct our research far more rigorously, and to broaden the scope of the research to cover various options we would not have been able to consider with a smaller in-house facility."

"The availability of the ANFF has ensured that we cover many more possible options than we would have been capable of achieving otherwise. From a scientific/ engineering point of view this has ensured that the outcomes of our CTD project will be based on the most recent research and the most appropriate data."

Phoenix have recently based one of their researchers, Dr Laurence Bell, at the NSW node full time.

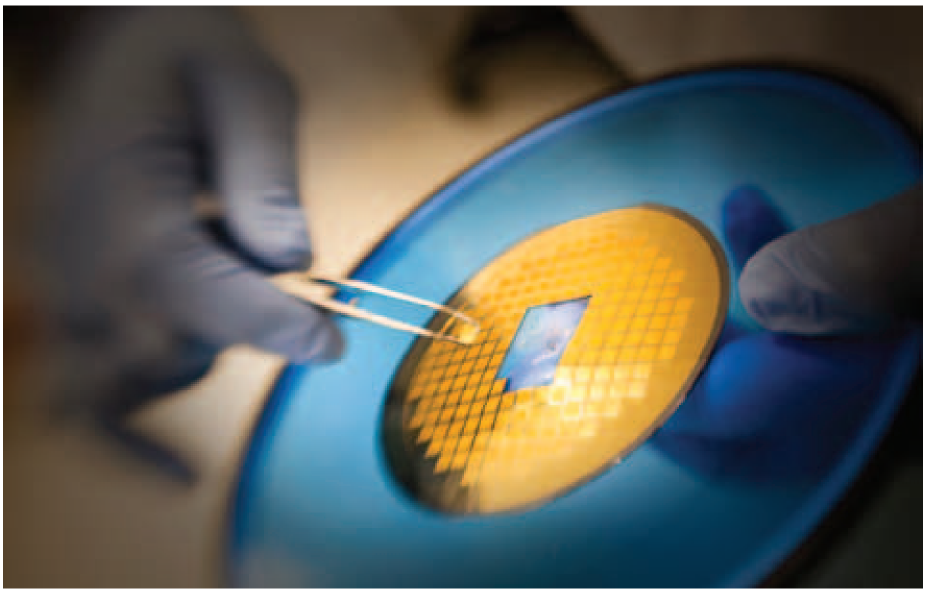
Dr Laurence Bell, Pheonix Engineering Systems at the NSW node

Aqua Diagnostic:

Aqua Diagnostic's business mission is to become an international supplier of innovative analysis technologies, and has recently commercialised a range of product forms based on its PeCOD™ technology for COD analysis (Chemical Oxygen Demand). With its initial focus on the rapidly growing global market of Water Management, Aqua Diagnostic is able to offer the industry significant improvements in both the quality and economy of water management.

The PeCOD™ technology is able to photoelectrochemically generate an electrical signal that directly correlates, via mass balance, with the oxidisable organic species contained in natural or waste-water samples. The core of the technology is the ability of the UV-activated nano-particulate photocatalyst semi-conductive electrode to create a high oxidation potential which ensures complete oxidation of all oxidisable organic species, and the ability to capture and measure the resultant photo-current.

Aqua Diagnostic obtained a STIUP grant for $50,000 from the Victorian Government in late 2012 to work with MCN and Swinburne University to investigate new manufacturing and quality assurance systems for their sensors.



Manufacture of the Nanopatch at ANFF-Q. Credit: University of QLD

THE SINGLE ATOM QUANTUM BIT

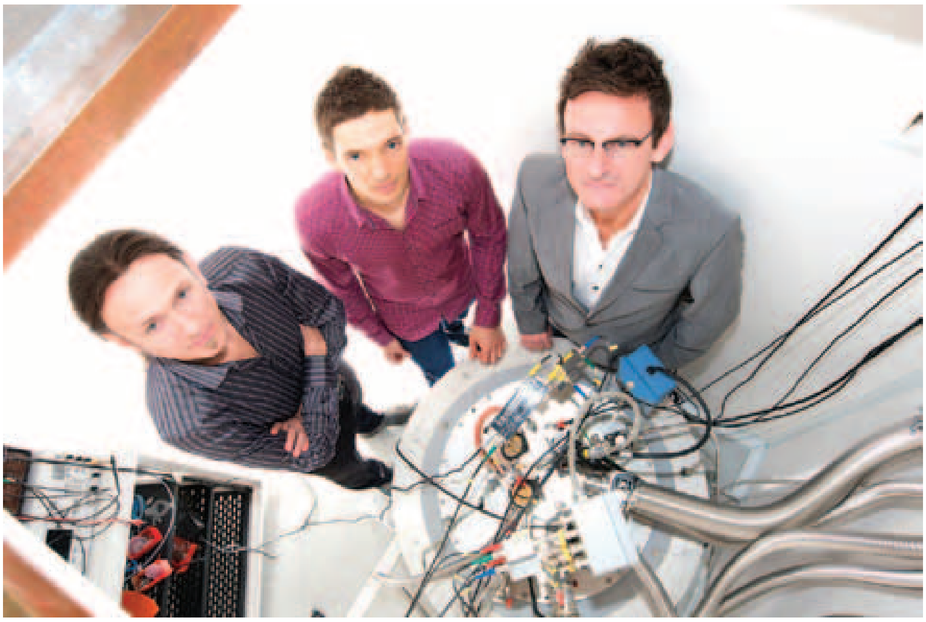
Andrew Dzurak, Andrea Morello and Jarryd Pla, NSW node - UNSW

Quantum computers promise to solve complex problems that are currently impossible on even the world's largest supercomputers. Data-intensive problems such as cracking modern encryption codes, searching large or complex databases, and modelling biological molecules and drugs would all be easy work for a quantum computer.

In 1998 Dr Bruce Kane, then a postdoctoral researcher at UNSW, published a concept for a quantum computer in the prestigious scientific journal Nature. This accelerated an international race to build a quantum computer – a goal highly prized by researchers around the world since many believe it will be the next significant technological leap in computing technology since the discovery of the semiconductor transistor in 1947. In current computing, information is represented by classical bits, which are always either a 0 or a 1 – the equivalent to a semiconductor transistor device being switched on or off. For quantum computing you need an equivalent, such as the direction that electrons spin around an atom. A clockwise (or "up") spin would represent a 1 and a counter-clockwise (or downward) spin would represent a 0. These are known as quantum bits, or qubits.

A holy grail would be to make these qubits from silicon as there already exists a trillion dollar silicon industry that can help bring these computers into society.

In 2000, a research centre now known as the Centre for Quantum Computation and Communication Technology (CQC^{2}T) was established at UNSW. This centre positioned Australia at the forefront of the international race to construct a working quantum computer and now has more than 150 researchers in Australia. Between 2000 and 2009 the group has published hundreds of papers on single atom nanotechnologies. Like many such centres, ANFF nodes were established to support their research. The NSW node of ANFF, based at UNSW, specialises in fabrication for high resolution electronics and has been key in keeping CQC^{2}T at the front of the race since 2007. In 2010 ANFF-NSW node director Prof. Andrew Dzurak, and CQC^{2}T project manager Dr Andrea Morello made the first giant leap towards a working silicon quantum computer. They fabricated a device that demonstrated the ability to detect the direction electrons spun around a phosphorous atom – they could read 0 or 1.



Project leaders Andrew Dzurak (left) and Andrea Morello (right), with PhD student Jarryd Pla (centre). Credit: UNSW

The significance of the finding was demonstrated by its publication in "Nature" and also winning the pair a prestigious Australian Museum "Eureka Prize". Despite some prior doubt from the greater scientific community, the concept of a silicon based quantum computer was now a reality. However, reading the spin only solves half of the qubit problem. To be useful it also needs a way of setting the spin state, or writing the data. In September 2012, UNSW PhD student Jarryd Pla, his supervisor Dr Morello, and Professor Dzurak published the second giant leap for silicon quantum computing – they learned to write 0 and 1.

"For the first time, we have demonstrated the ability to represent and manipulate data on the spin to form a quantum bit, or 'qubit', the basic unit of data for a quantum computer," says Professor Andrew Dzurak, Director of the NSW node of ANFF at the University of New South Wales. "This really is the key advance towards realising a silicon quantum computer based on single atoms."

ANFF would like to congratulate Mr Pla, Dr Morello and Prof Dzurak, as well as everyone at CQC^{2}T for their achievements. The global significance of this development has been recognized with Nature once again publishing the group's research.

Having demonstrated a working qubit in silicon, there is still a long road ahead for the Centre. The next steps will involve combining individual qubits and demonstrating their function as a logic gate, then clustering many of these together to form a chip, the heart of a quantum computer.

BULLET PROOF GRAPHENE

Geoff Spinks and Gordon Wallace, Materials node - University of Wollongong

Researchers at the ANFF Materials node have used graphene to develop a new composite material that can produce the toughest fibres to date, even tougher than spider silk and Kevlar.

The latest discovery in the nano world of carbon, graphene, has proven to be an amazing building block for advanced materials. The new graphene composite can then be wet-spun into fibres with potential applications in bullet-proof

From left: Prof Geoff Spinks, Dr Sanjeev Gambhir, Prof Gordon Wallace. Credit: Materials node, University of Wollongong

vests and reinforcements for advanced composite materials.

Researchers at the University of Wollongong base of the ARC Centre of Excellence for Electromaterials Science (ACES) have shown that graphene can work just as well as the more common toughening agent, carbon nanotubes, in polymer composites. Graphene is also a much cheaper material and can be produced easily in large quantities. This work was published in Nature Communications in February 2012.

ACES Senior Researcher and paper co-author Professor Geoff Spinks from ACES said that the ratio of graphene to carbon nanotubes was a key factor in development of the composite.

"Quite surprisingly, we found that a "magic mixture" of equal parts carbon nanotubes and graphene added to the polymer gave exceptionally high toughness," said Professor Spinks.

"Fibres made with other combinations of these materials were not especially tough at all."

The super tough fibres can be produced easily by a wet-spinning method and can be readily up-scaled. In this case, fibres were spun by collaborators at the Centre for Bio-Artificial Muscle in Hanyang University, Korea.

"These international collaborations are critical for effective and efficient progress at the cutting edge of science," said Professor Gordon Wallace, Director of the Materials node.

"This particular project benefitted from the supply of the graphene building blocks using a process invented here in Australia and further developed using the skills and facilities available the Australian National Fabrication Facility - Materials node."

The team has also supplied graphene materials for other research activities in the USA, Korea and France.

WHEN ART AND NANOTECHNOLOGY MEET

Paula Dawson, UNSW College of Fine Arts at the NSW node - UNSW

Australian artists and ANFF engineers have made a step towards bringing holographic television content to your living room.

They have successfully produced a computer generated hologram the equivalent of a 3 x 3 mm zone of one still frame of holographic television.

NSW node process engineer Joanna Szymanska said "We engineered a 3D electron beam lithography (EBL) process using low contrast resist and our Raith EBL facility. Using a 2D digital image, we were able to pattern a 200nm resolution hologram fringe pattern to reproduce the digitally created test image."

The work represents a key success in the "Holoshop" project led by Paula Dawson from the UNSW College of Fine Arts. Her ARC Discovery project aims to create a set of innovative technologies and software for creating specific content for holographic TV. This technology will also be applicable to other 3D display systems, such as monitors with haptic tools which enable the direct hand-drawing of subjects.

The ANFF-NSW team is a world leader in EBL fabrication, a nanotechnology for patterning features smaller than the

Artists impression of a 3D display or holographic TV technology. Scientist Joanna Szymanska speaking to Artist Paula Dawson from her laboratory through a 3D projector. Credit: NSW node, University of NSW

wavelength of light. This expertise led Paula to the ANFF-NSW clean rooms and EBL expert Joanna Szymanska.

This collaborative project brings together researchers from Arts (COFA), IT, Physics and Electrical Engineering. ANFF anticipates it will continue to play a significant role in the technological development of what might be a revolution in digital media.

NEXT GENERATION MEMORY DEVICES FOR PORTABLE ELECTRONICS

Robert Elliman with Applied Materials Inc., ACT node - Australian National University

ANFF researchers have partnered with a multi-billion dollar leader in semiconductor equipment manufacture, Applied Materials Inc (NASDAQ:AMAT), to help develop a new generation of non-volatile memory devices for portable electronics.

Prof Robert Elliman, Principal Investigator on the project from the Australian National University, home to the ACT node of ANFF, said: "Specifically the project aims to develop techniques for improving the reliability and endurance of a new class of non-volatile memory called resistive random access memory (ReRAM). These have the potential to provide smaller, faster, and more energy efficient memory that is essential for next-generation portable electronic devices."

The ion implantation facility at the ACT node of ANFF is key in developing next generation memory devices. The project is funded through an ARC Industry Linkage grant with Varian Semiconductor Equipment Associates who were acquired by Applied Materials in November 2011.

Ion implantation facility at the ACT node. Credit: Australian National University

Prof Elliman said: "The Linkage grant with Applied Materials/Varian is turning out to be very successful and may lead to further engagement with the company. The ANFF facilities and expertise have, and will continue to play a critical role in this work."

Applied Materials, Inc. is the global leader in providing innovative equipment, services and software to enable the manufacture of advanced semiconductor devices, flat panel displays and solar photovoltaic products.

The interaction with Advanced Materials provides an important opportunity for Australian scientists and engineers to work at the forefront of semiconductor research, and to showcase Australian expertise and knowhow.

3D NANO-LITHOGRAPHY: COMBINED ELECTRON AND ION BEAM FABRICATION

Saulius Juodkazis with Raith GmbH, Victorian node - Swinburne University

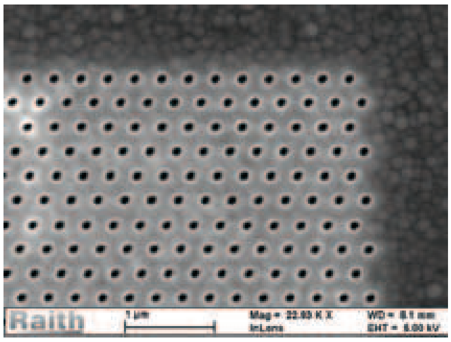
A world leader in nanotechnology, Raith GmbH, have partnered with ANFF-Vic node at Swinburne University to introduce a third dimension to nano-fabrication.

Through a Joint Development Program between Swinburne and Raith and partially funded through an ARC Industry Linkage grant, the team at Swinburne will develop a means of 3D patterning by combining electron beam lithography (2D) and ion beam milling (3D) with a precision of several nanometres.

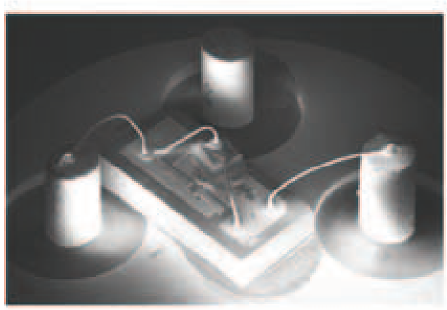
ANFF's ion and electron beam lithography capabilities will create the structures that enable light to be controlled at the nano-scale opening new possibilities for ground breaking applications in photonics and sensing.

One example is the creation of a 3D chiral nanostructure. When it interacts with light (photons) it has an angular momentum (spin and orbital) defined by a circular polarization and a spiralling wave front. 3D structures could be used in discriminating left and right chiral molecules (glucose, DNA, etc) to create a new generation of biosensors.

Other applications include bio-and environmental sensing, and light harvesting for solar cells.



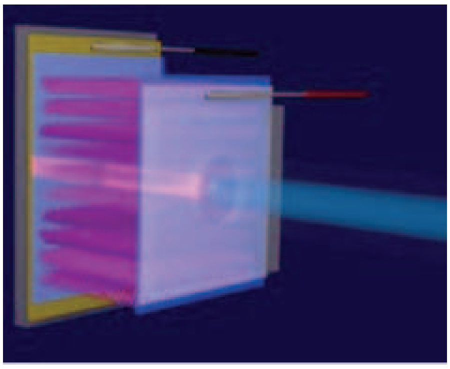
Light-extraction nanostructure on the surface of an LED device.



*LED device.
Credit: Victorian node, Swinburne University of Technology*

NEW SENSORS AT THE TIP OF YOUR FIBRE

Zourab Brodzeli, Leonardo Silvestri and François Ladouceur, NSW node - commercialising their technology at UNSW



Artists impression of the sensor on the tip of an optic fibre. Credit: UNSW

A new photonic device could enable sensing in harsh environments where traditional electrical-based devices fail.

Ultrasensitive hydrophones, pressure monitors for oil and gas pipe lines, flammable gas detection in mines, voltage sensors for high power electrical lines or vibration sensors for power generation turbines, are all applications that this platform technology could realise.

The device uses an optical transducer based on liquid crystals and nano-materials. The resilience of this device to harsh environments comes from the fact that the sensor lies at the tip of an optic fibre rather than in an electronic device. As it uses light it is immune to electrical interference. Being attached to an optic fibre multiple sensors can run out over a long distance.

The UNSW School of Electrical Engineering in collaboration with Hong Kong University of Science and Technology (HKUST) developed this technology with the support of ANFF capabilities at the NSW node.

A lab scale prototype has been made and on-going work at the NSW node and the UNSW School of Electrical Engineering and Telecommunications is developing the device towards a number of application specific products.

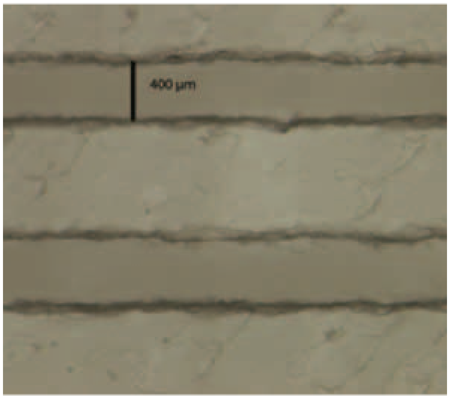
The Photonics group at UNSW are at the early stage of commercialisation.

CAPTURING THE WILD MUSSEL SPAT

Varsha Lal and the Queenscliff Mussel Hatchery (Department of Primary Industries), Victorian node - MCN

3-dimensional printing has been used to fabricate surface textures that enhance the settlement of mussel larvae. Ultimately this will improve the profitability of the mussel farming industry through improved capture of wild mussel spat.

This work was conducted for Dr Andrew Poole (CSIRO Wealth from Oceans Flagship) and Prof Rocky de Nys (James Cook University). The Eden 260V 3D printing system at MCN is capable of providing an easy to use, fast, clean and accurate prototype for a design to manufacturing product cycle. This was ideal for the production of a polymer micro-structured surface, which allowed the collaborators to immediately change the texture design and produce new polymer surfaces to suit their research requirements.



3D printed structure to capture mussel spat. Credit: Victorian node, MCN

The image shows the 400µm grooves with 800µm spacing as a polymer structure that was produced on the 3-dimensional printing system. These surfaces are currently being used for trials at Queenscliff Mussel Hatchery (Department of Primary Industries).

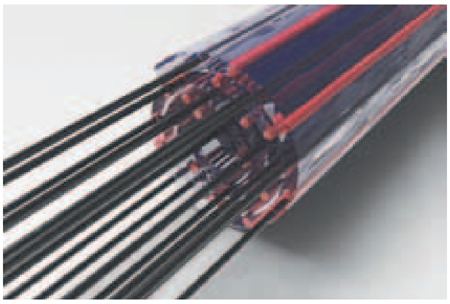
GOOD HEALTH

The world's best solutions to health problems come from a multidisciplinary approach. ANFF has applied its capabilities in fields such as 3D printing, optics, materials science, semiconductor processing and microfluidics to health related problems and come up with a range of unique solutions. These solutions will save lives and improve the health of all Australians.

An optical fibre flu sensor
Credit: IPAS, University of Adelaide

NERVE REGENERATION DEVICE HAS POTENTIAL TO HELP MILLIONS

Robert Kapsa, Materials node – University of Wollongong



Schematic showing conjugate of a 3D printed support for nerve regeneration. Credit: Materials node, University of Wollongong

A new nerve repair device has the potential to help millions of people who lose nerve tissue function due to trauma, surgery and disease.

An international team of researchers led by the ARC Centre of Excellence for Electromaterials Science (ACES) have used a key mix of materials developed at the ANFF Materials node at the University of Wollongong to develop a nerve repair device that is showing promising results for recovery of sensation following significant nerve damage.

"The conduit has been designed to specifically promote the growth of cells that make nerves function correctly, in preference to cells that would normally promote the growth of cells that cause scar tissue to form in injured nerves," said ACES Bionics Program co-leader Assoc. Prof. Robert Kapsa.

"This has been achieved through careful selection of materials and fabrication processes that collectively deliver a nerve repair conduit that promotes regeneration of damaged nerve through several independent repair processes."

Conventional methods of treating significant nerve damage over 2 cm long in the peripheral nervous system (outside of the brain and spinal cord) usually involve nerve grafts harvested from elsewhere in the body. Functional recovery is often poor with this treatment and loss of sensation occurs from the area where the nerve graft was harvested.

In this device, the materials created at the ANFF Materials node are specifically matched to promote growth of neurons and supporting cells. The new conduit device has been used in animal trials for three months at St Vincent's Hospital Melbourne, with results suggesting that it can restore feeling to the damaged area.

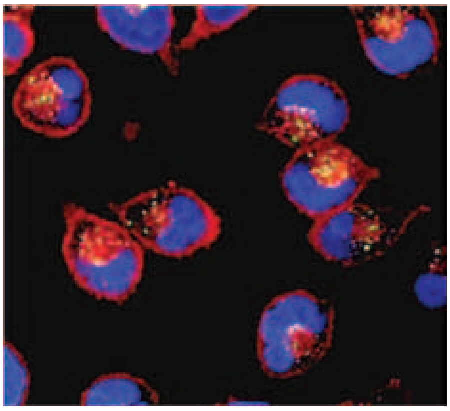
"The device has undergone several improvement stages and is now ready for final pre-clinical studies that will identify its full potential for promoting effective repair of damaged nerves," said Assoc. Prof. Kapsa.

"In addition to its applications in assisting people who lose nerve tissue function; this exciting development has the potential to be applied in other Bionics applications where direction of stimulated nerve growth is required."

These results have recently been published in the Journal of Neural Engineering.

GUERRILLA TACTICS IN THE WAR AGAINST CANCER

Dr Christina Cortez-Jugo, ANFF Victorian node - Monash University



Confocal microscope image showing the uptake of fluorescently-labelled pore forming proteins (green) by cancer cells (membrane in red, nuclei in blue). Credit: Victorian node, Monash University

Introducing therapeutic molecules into cancer cells, without harming healthy cells, remains a largely unsolved technological challenge.

A project at MCN lead by Christina Cortez-Jugo from Monash University aims to address this problem by developing sophisticated, nanoscale therapeutic carriers, with improved efficacy and specificity.

The project will investigate the use of pore forming proteins, which have the ability to temporarily puncture cells, to facilitate the transport of therapeutic molecules inside cancer cells. The facilities at MCN are important for this work as they allow the efficient integration of life science with material science research. The scientific and technological advances in drug delivery and nanomedicine that would be enabled by this work are poised to revolutionise cancer treatment and lead to improved healthcare.

TWISTING ARTIFICIAL MUSCLES

Geoff Spinks, Materials node - University of Wollongong

The possibility of a doctor using tiny robots in your body to diagnose and treat medical conditions is one step closer to becoming reality, with the development of artificial muscles small and strong enough to push tiny Nanobots along.

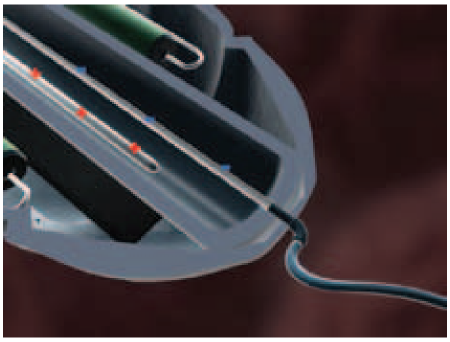
Although Nanorobots (Nanobots) have received much attention for the potential medical use in the body, such as cancer fighting, drug delivery and parasite removal, one major hurdle in their development has been the issue of how to propel them along in the bloodstream.

A collaborative team of researchers from the ARC Centre of Excellence for Electromaterials Science (ACES), part of the Materials node, have developed a new twisting artificial muscle that could be used for propelling nanobots. The muscles use very tough and highly flexible yarns of carbon nanotubes (nanoscale cylinders of carbon), which are twist-spun into the required form. When voltage is applied, the yarns rotate up to 600 revolutions per minute, then rotate in reverse when the voltage is changed.

Due to their complexity, conventional motors are very difficult to miniaturise, making them unsuitable for use in nonorobotics. The twisting artificial muscles, on the other hand, are simple and inexpensive to construct either in very long, or in millimetre lengths.

"This new, giant, rotating type of actuation will open up lots of new opportunities for micro machines," said Prof Geoff Spinks, ACES Chief Investigator.

Similar twisting muscles are found in nature, such as octopus limbs and elephant trunks. In these appendages, helically wound muscle fibres rotate by contracting against an incompressible, bone-less core. The rotation in the helically wound carbon nanotubes used for the twisting artificial muscles is caused by an increase of liquid electrolyte volume within the yarn.



Artists impression of a twisting artificial muscle in a nanorobot. Credit: Materials node, University of Wollongong

DETECTION OF CANCER CELLS IN A MICROFLUIDIC DEVICE

Benjamin Thierry, SA node - University of South Australia

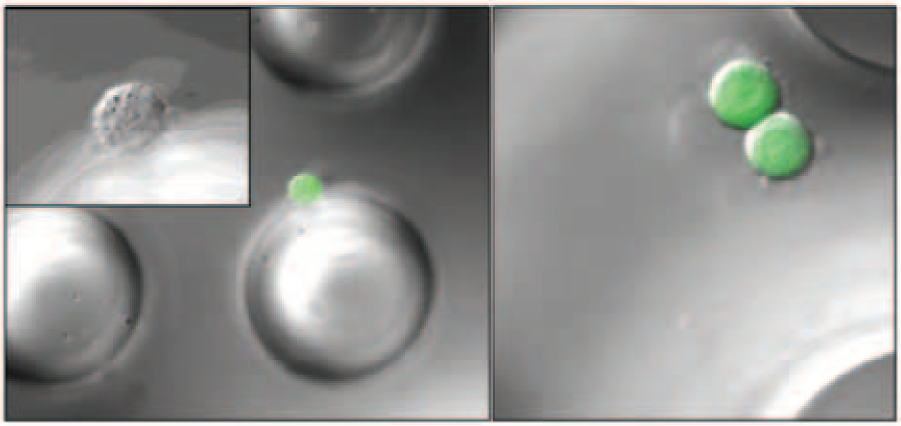
Breast cancer is the leading cause of cancer-related mortality in women. The common HER2 status of a breast cancer is primarily responsible for this disease being the most aggressive of all.

A device fabricated at ANFF could provide an ultra-sensitive early-detection system for free cancer cells circulating in peripheral blood, as well cells over expressing HER2 proteins, an indicator of the HER2 status.

Associate Professor Benjamin Thierry pioneered the microfluidic device in the ANFF-SA laboratories at the University of South Australia.

Patient's blood would be introduced into the microfluidic device. The blood would come into contact with 3D features in the device coated with specific monoclonal antibodies. Select cancer cells will attach to the antibody and can be later identified using a confocal microscope (see image).

"This technique has proven effective in detecting very low concentrations of cancer cells, around 2-3 per milliliter of blood. It provides an opportunity to develop a more reliable means of diagnosis than present methods, which have frequent false-negative readings," said Thierry. "It is also less disruptive to the tumour as it doesn't require a biopsy."



Cancer cells attached to antibody coated cylinders in a microfluidic device. Green indicates cells over-expressing the HER 2 gene. Credit: SA node, University of South Australia.

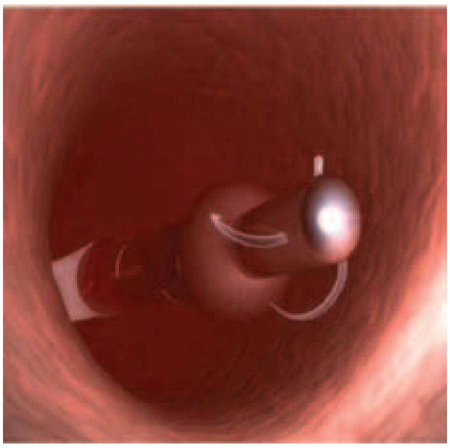
ANFF laboratories have not only helped make the prototype, they have also engineered the device such that it can be produced on a large scale. It is made from PDMS, a cheap polymer that can be molded into the device from a master fabricated using traditional semiconductor processing techniques. The most expensive part of the process is coating the surface with antibodies.

"Being able to manufacture cheap disposable devices will make this early detection system easily accessible to oncologists around the world," said Thierry.

"In the future, such devices could enable doctors to select the most appropriate and personalized therapy to fight metastatic cancer and significantly improve patient care."

MICROROBOTS THAT SWIM IN HUMAN ARTERIES

James Friend, Victorian node - Royal Melbourne Institute of Technology (RMIT)



An ultrasonic motor designed to navigate a micro-robot through human arteries. Credit: Victorian node, RMIT

Microrobots are making minimally invasive vascular surgery (MIVS) less risky.

A tiny 240 µm-diameter ultrasonic motor designed to navigate a micro-robot through human arteries has been fabricated at the ANFF. The technology, developed by Professor James Friend of the Melbourne Centre for Nanofabrication, is designed to assist surgeons whilst performing MIVS procedures. Medical specialists will be able to reach previously inaccessible arteries in a shorter time frame than current procedures.

This technology has several advantages over existing MIVS techniques that traditionally have a failure rate of up to 40%. The first major advantage is that the catheter guidewire is actively navigated using a motor, rather than being forcibly pushed through arterial passages. This is likely to result in a reduction in injury to vascular membranes. Further, complex cerebral events (such as an aneurism) have a time-sensitive treatment window. This technology allows medical specialists to locate and treat the cerebral event up to 20% faster than conventional MIVS procedures.

Professor Friend predicts that up to 85% of 350 µm cerebral arteries can be accessed easily with this microrobot. Combined with an additional 4 cm of reach, this technology provides opportunities for treatment well beyond the range of arteries previously accessible.

Components of the microrobot are about the width of a human hair. The motor comprises a stainless steel ball rotor mounted on a laser machined precision tube, prepared at the OptoFab node of ANFF.

The stainless steel ball is held in place using a magnetic payload generated from a permanent magnet. According to Professor Friend, the micro-sized motor generates rotational motion from a combination of orthogonal and longitudinal vibration modes. The drive's input signals are provided via two 50 µm diameter wires. The micromotor assembly is designed to be affixed to standard catheter tips, providing smooth navigation through vascular pathways.

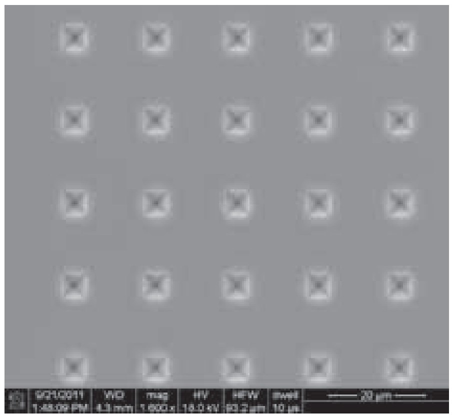
RAPID POINT-OF-CARE SENSOR FOR INFECTIOUS DISEASE DISCRIMINATION

Sasi Kandasamy with Biodetectors Pty Ltd supported by the Small Technologies Industry Uptake Program (STIUP), Victorian node - MCN

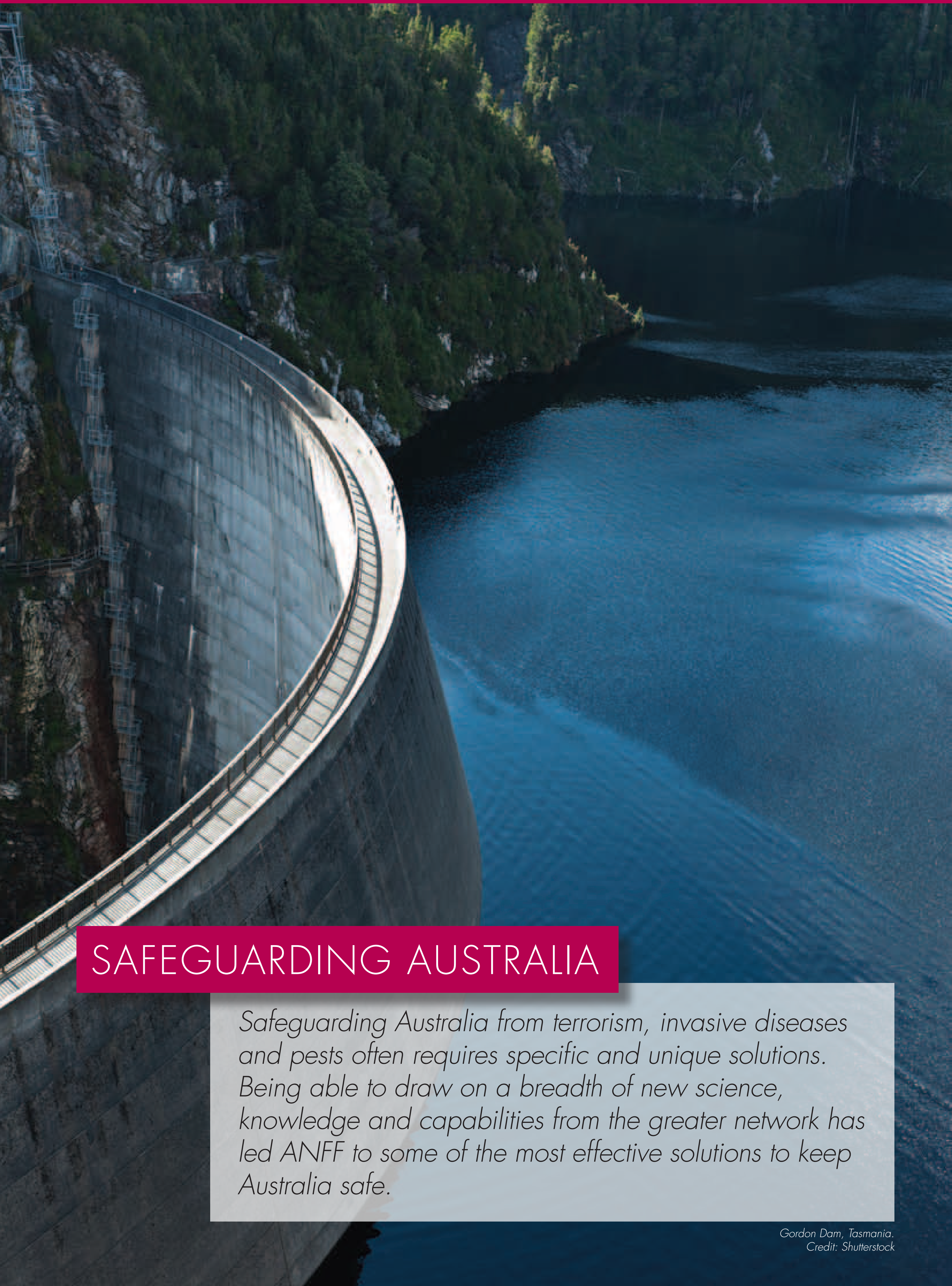
Bead-based technologies are used in many applications including genetic screening, diagnostics, drug discovery and protein analysis. They allow for fast, specific, high-throughput analysis of target molecules.

The Victorian node of ANFF, the MCN, is supporting a project through device design, prototype fabrication and optical assay verification. The proposed technology of anisotropically etched pyramidal wells on a silicon substrate, and its subsequent use as a template for the fluorescent bead arrays, is a simple, versatile and inexpensive method for the fabrication of high-density bead arrays. Using the micro/nano fabrication platforms available at the MCN, arrays of pyramidal wells have been patterned and fabricated to allow fluorescent bead molecules to be assembled within them.

The figure shows an SEM image of an array of fabricated pyramid wells (6um width) on a silicon master. This work will help demonstrate the potential to create high density arrays with better readout capabilities and superior signal to noise ratio than those achievable with classical microarrays.



Array of pyramidal wells. Credit: Victorian node, MCN



SAFEGUARDING AUSTRALIA

Safeguarding Australia from terrorism, invasive diseases and pests often requires specific and unique solutions. Being able to draw on a breadth of new science, knowledge and capabilities from the greater network has led ANFF to some of the most effective solutions to keep Australia safe.

Gordon Dam, Tasmania.
Credit: Shutterstock

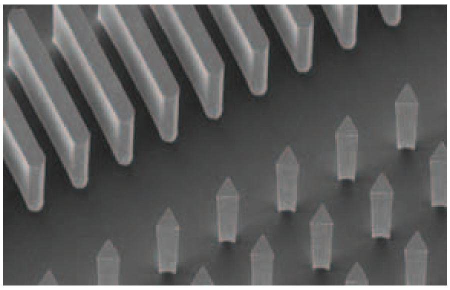
PROTECTING THE NATIONAL WATER SUPPLY

James Friend, Sean Langelier and Nick Glass, Victorian node - RMIT

Contaminated water used for drinking, cooking, and washing is responsible for between 2.2 and 5 million deaths a year. Sadly, this problem is worldwide, affecting both the developing and developed worlds - Sydney's 1998 water crisis is an example of the latter.

Professor James Friend and his group from RMIT, part of the Victorian node of ANFF, may have a solution – a microfluidic device designed for pathogen detection within community water supplies.

The device is a fluid separation element that uses surface acoustic waves and a nanostructured surface to actively filter harmful disease causing pathogens from water passing through it. A secondary stage exposes the filtrand to an integrated optical detection system to identify the pathogen.



Bacteria separation element fabricated using the deep reactive ion etcher. Credit: Victorian node, MCN

Cryptosporidium Parvum Bacterium, the pathogen responsible for the 1998 Sydney water crisis, has been successfully detected using this device.

The self-contained sensor is inexpensive enough to produce in large volumes and provides sufficient veracity to quickly target and eliminate the source of a future outbreak. It has been transposed from design to development at the Melbourne Centre for Nanofabrication (MCN), headquarters of the Victorian node of ANFF.

The work forms part of a cluster collaboration between, MCN, CSIRO and a number of Australian Universities to create an integrated device.

ANFF IN THE WAR AGAINST TERROR

Dr Yonggang Zhu, Victorian node - CSIRO

A device that can quickly and reliably detect sarin, the colourless and odourless gas responsible for the 1995 terrorist attack on the Tokyo subway in 1995, has been developed at ANFF.

The "lab-on-a-chip" device looks set to boost national security and potentially save lives. Being compact it is a field-deployable chemical detector that can 'fingerprint' sarin and other chemical warfare agents with high sensitivity, reliability and unprecedented speed.

Dr Yonggang Zhu, of CSIRO has won the 2012 Australian Museum Eureka Science Prize for Outstanding Science in Support of Defence or National Security for his efforts developing this technology. The prize was sponsored by the Defence Science and Technology Organisation and the win was announced by Defence Science Minister Warren Snowdon on 28th of August 2012.

Current methods of detecting sarin and other chemical warfare agents, such as gas chromatography, are difficult to use, have a high rate of false positive readings, and are too bulky to be deployed in the field. The prototype consists of a microfluidic device a few centimetres in size. With a sample of water, soil or a swab, it has demonstrated effective in generating highly accurate readings in approximately 30 seconds.

As well as being a novel technology the chip has been made using plastic with processes amenable to large-scale manufacture. This will allow the devices to be cheap and disposable. It will also mean that it can be deployed on a broad scale, all soldiers in an army or trains in a network could carry these devices.

"We know the business-end of the chip works. With further miniaturisation of the electronics and power supply, we expect to see a device the size of a mobile phone" said Dr Zhu.

"We also hope to integrate a wireless communication capability into the sensor board, for real-time monitoring of toxic chemicals, and to provide an early warning of a terrorist attack."

Dr Yonggang Zhu receiving the Eureka award from Chief Defence Scientist Dr Alex Zelinsky. Credit: Victorian node. CSIRO

This is an Australian-owned technology, with the main components manufactured using ANFF facilities. Dr Zhu is a Technology Fellow at the Melbourne Centre for Nanofabrication in the ANFF Victorian node. ANFF capabilities will be key in making this technology available to national security and defence agencies in the near future.

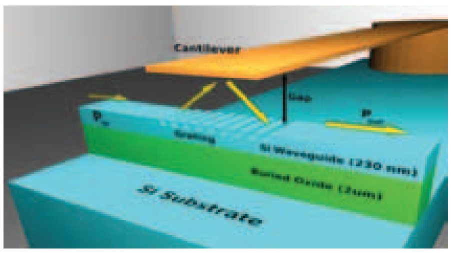
MEMS MULTI-ANALYTE CHEMICAL SENSOR

Mariusz Martyniuk, WA node - University of Western Australia

ANFF-WA scientists have developed a platform technology that could be used for the non-invasive detection of lung cancer.

The micro-electro-mechanical-system (MEMS) uses optical waveguides to produce a signal for very minute cantilever movements (better than Atomic Force Microscope), which can measure forces as low as 1 zepto-gram (10-21 g). The design is amenable to the fabrication of large arrays of micro-cantilevers and eliminates the requirement for alignment in the optical readout (as in the AFM platform).

Combined with a surface functionalisation of the cantilevers, multi-analyte chemical sensing is possible and would be suitable for applications ranging from pesticide detection, to wine quality analysis, to non-invasive lung cancer detection.



Cantilever with optical displacement sensor capibilities. Credit: Western Australia node, University of Western Australia

BRINGING COLOUR VISION TO INFRARED SENSING

Lorenzo Faraone, WA node - University of Western Australia

Biomedical imaging, environmental monitoring, mining, viticulture, agriculture and defence are some of the industries set to benefit from a platform technology being developed at the University of Western Australia.

The system is the equivalent of a digital colour video camera, but operating in the infrared part of the spectrum rather than the visible. It is a spectrometer that measures light energy at many separate infrared wavelengths, not just intensity that produces 'black and white' in regular infra red night vision. Using ANFF facilities, these spectrometers have been miniaturised essentially producing a 'spectrometer on a chip'. The technology is now lightweight, robust, compact, fast, accurate and inexpensive.

Farmers have traditionally used laboratory infrared spectroscopy to analyse carbon and nitrogen concentrations in soils, and levels of protein, starch, oil and moisture in grains. A major factor limiting the widespread use of the technology in the field has been the lack of a robust, low-cost portable instrument for acquiring data.

Credit: NASA

Lightweight, hand-held detectors containing the spectrometer-on-a chip will enable farmers to conduct real-time soil monitoring and characterisation of grains during harvesting. The group is now fabricating linear infrared detector arrays for commercial applications such as airborne imaging.

Infrared airborne imaging allows not only visualisation of features on the ground but also easy identification of constituents of the ground. Through the spectral signatures of the surface materials, one can rapidly identify and accurately map the surface. This is highly attractive for mineral exploration, energy resources, coastal mapping and environmental monitoring.

The sensors will also assist soldiers operating in cluttered environments and urban areas, enabling them to scan for threats and targets from safer distances or through dust or smoke.

GOLD, LASERS AND NANOPARTICLES

OptoFab node – Macquarie University

Ultra-sensitive hydrophones for submarines, radiation-free cancer therapy and high efficiency solar cells are just three examples of many technologies evolving from new methods of fabricating gold nanoparticles.

The OptoFab node of ANFF has developed a new process to produce gold nanoparticles in large quantities with less contamination and a higher degree of control over their size than existing techniques.

This breakthrough will support all of the rapidly evolving fields that use nanoparticles including: medicine and biosciences (cancer therapies), energy technology (fuel cells and solar cells), environmental technology (materials cycles and disposals), defence (hydrophones), photonics, and information technology.

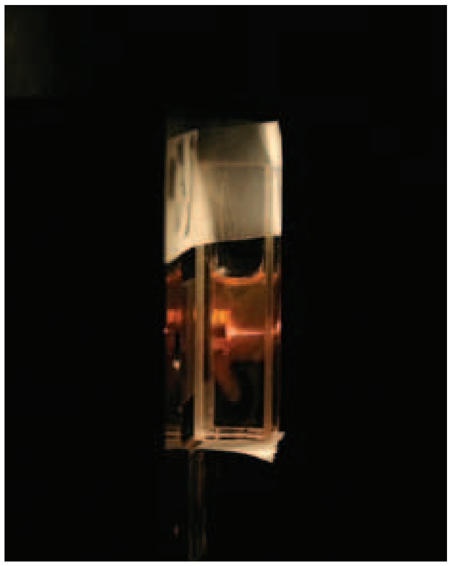
The process uses laser ablation, a field in which the OptoFab node hold significant expertise. ANFF's femtosecond laser facility irradiates a gold target that is immersed in a solution. The interaction of the electric field from the laser is so strong that it can remove a single piece of gold from the surface, a nanoparticle. When the laser is scanned across the surface of the gold nanoparticles are ejected into the solution in large quantities. This solution can then be centrifuged to produce a concentrated suspension.

"A key to this process is understanding the effect of laser parameters, such as pulse energy, repetition frequency and beam spot size on the size and distribution of the nanoparticles" said Dr Ben Johnston, facility manager of the OptoFab node from Macquarie University.

"This has allowed us to produce narrow size distributions of nanoparticle suspensions for the specific applications our collaborators are after."

This optimised process has been published in the academic journals Langmuir and the Journal of Nanoparticle Research. The breakthrough is expected to accelerate the technology development for OptoFab's collaborators both within the ANFF network as well as others throughout Australia.

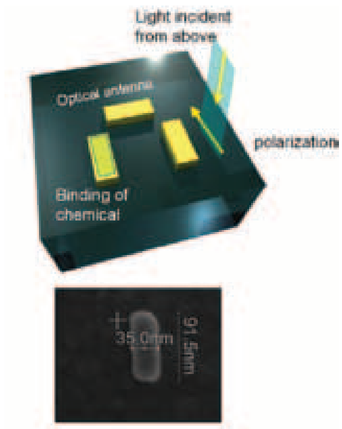
Work is ongoing to extend the technique to the fabrication of other nanoparticles such as silver and titanium.



Laser irradiating a gold target (from the right) to form a suspension of nanoparticles.
Credit: OptoFab node, Macquarie University.

NEW METHODS FOR DETECTING CHEMICALS AND BIOLOGICAL CONTAMINANTS

Tim Davis, Victorian node - MCN and CSIRO



A nanoscale structure created at the MCN using electron beam lithography. Credit: Victorian node, CSIRO

ANFF is developing new ways to detect chemicals and biological contaminants, for applications in environmental monitoring and biomedicine. Because different chemicals interact with light in different ways, we are investigating methods of using light to detect and identify different chemicals and biological materials.

The key issues are discrimination, being able to distinguish between similar chemicals or biologicals, and sensitivity - being able to sense low concentrations. The project at the MCN aims to address this problem by controlling the properties of light at the nanoscale, which we hope will lead to better molecule discrimination and sensitivity. In particular, we interact light with metallic nanostructures – these act like antennas for light. The facilities at the MCN are important as we need to fabricate the optical antennas at very small scales, well below the wavelength of light, and then combine them together to control the light and how it interacts with molecules.

Moreover, the technology has applications in other areas such as optical communications and improving solar energy conversion.

OPTIC FIBRES THAT CAN HEAR YOUR HEART BEAT

Richard Lwin, OptoFab node – University of Sydney

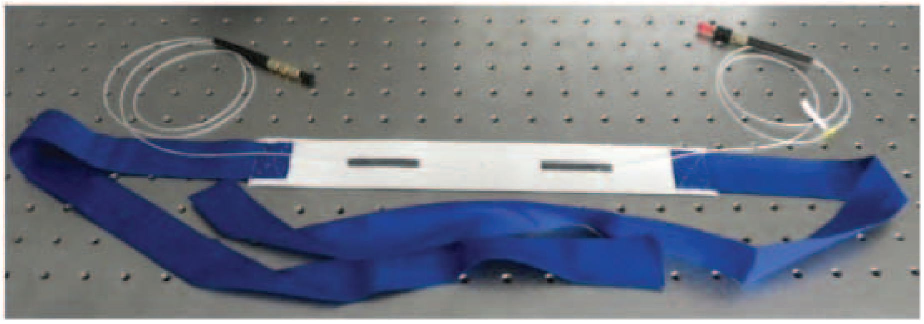
Engineering of fighter jets, smart clothes that can hear your heart beat and optimising the design of high performance sail boats, and are just a few innovations that have come from a new generation of optical fibre strain sensors developed at ANFF.

In the 2010 Americas cup a number of teams, including Alinghi 5 and BMW/Oracle, began using glass optic fibre Bragg grating (FBG) systems with over 100 sensors. These optic fibre sensors were laminated into carbon fibre components that might fail during racing conditions, such as the mast or boom. This helped the engineering team make the boats as light as possible and also provided a guide for the sailors sounding an alarm when they were pushing their boat too hard.

The sensors themselves are inside the optic fibre. They contain a "Bragg grating" or series of small notches that act as a mirror for a specific colour (or wavelength) of light. The colour that is reflected is very sensitive to the spacing of the notches and changes when the fibre is stretched. A detector at the end of the optic fibre measures this colour and converts it to a strain.

While glass FBG sensors are useful in high tech applications such as yacht racing and aeronautical engineering, the range of applications are limited by the mechanical properties of the glass, which are very stiff and will break under very little strain.

The OptoFab node of ANFF has developed a variation of the glass FBG



Prototype belt with an integrated polymer LPG strain sensor. Credit: University of Sydney

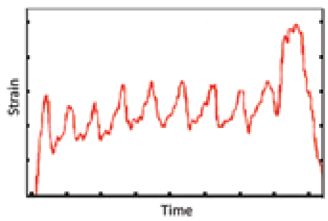
that has overcome these problems. The ultra-sensitive long period grating (LPG) sensor was made from a microstructured polymer optic fibre using ANFF's fibre draw tower facilities at the University of Sydney.

"These fibres have a Young's modulus approximately 25x lower (than glass) which means we can make the polymer LPG sensors at least 25x more sensitive than glass FBGs" said Dr Richard Lwin from the University of Sydney.

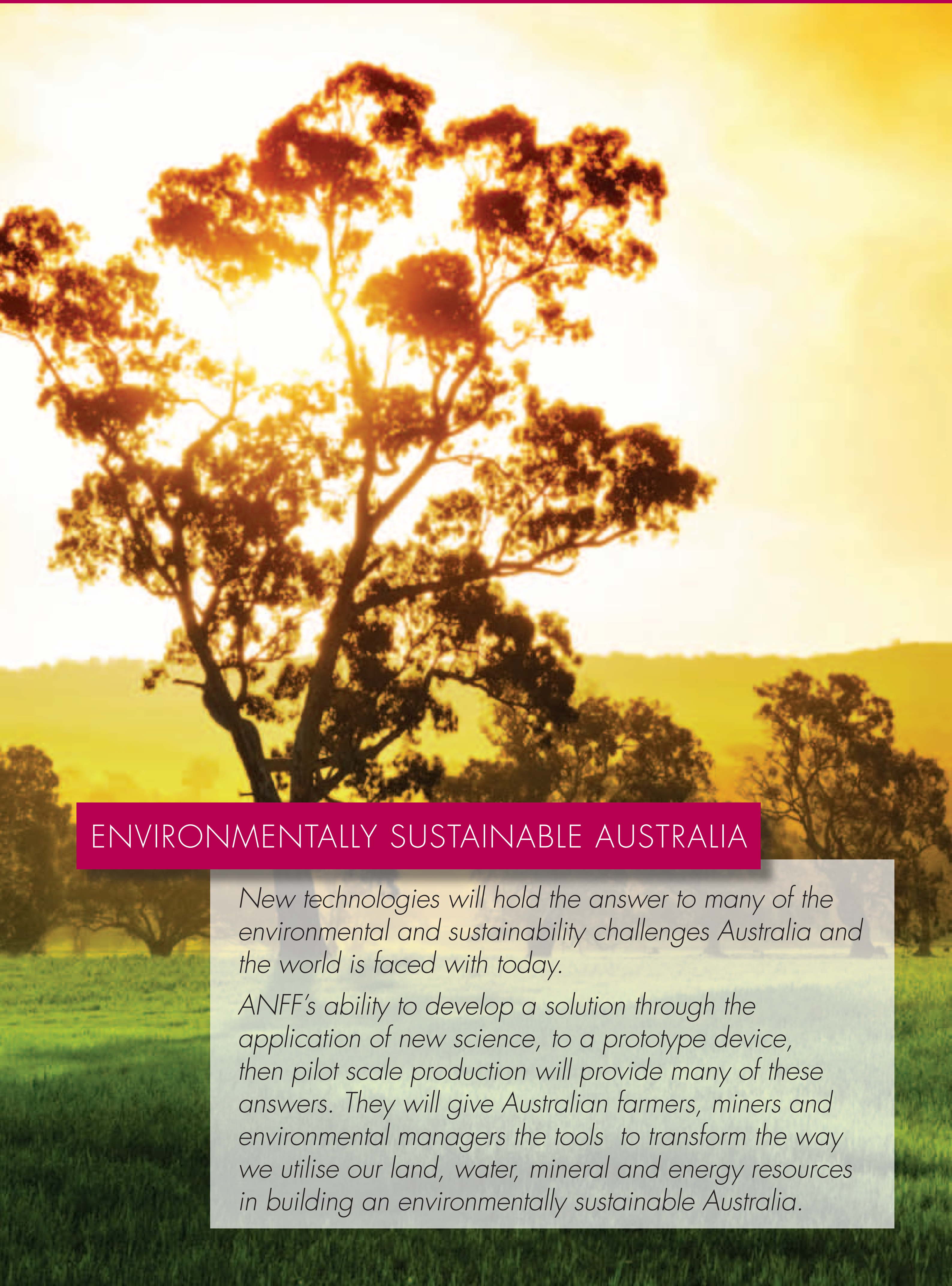
"They also have a much higher breaking strain meaning they can be used to measure strains more than order of magnitude higher than with glass FBGs."

In demonstrating the sensitivity of their new LPG sensor, fibres fabricated at OptoFab have been used to make a prototype heart rate monitor (pictured). Modifications of this design are underway to better integrate the device into clothing.

Following OptoFab's developments the application range of ultrasensitive LPG strain sensors is set to explode well beyond yacht racing and heart rate monitors. Some ideas already on the table are structural vibration monitors in building or bridge constructions, or bending limit detectors for electricity generating windmill blades.



Signal from the sensor showing the heart beat of the wearer.
Credit: University of Sydney



ENVIRONMENTALLY SUSTAINABLE AUSTRALIA

New technologies will hold the answer to many of the environmental and sustainability challenges Australia and the world is faced with today.

ANFF's ability to develop a solution through the application of new science, to a prototype device, then pilot scale production will provide many of these answers. They will give Australian farmers, miners and environmental managers the tools to transform the way we utilise our land, water, mineral and energy resources in building an environmentally sustainable Australia.

TURNING WATER INTO FUEL

Materials node - University of Wollongong

"Solar energy" means more than just electricity. It can be used to create fuel such as hydrogen that, unlike solar electricity, can be stored and used when the sun goes down. Hydrogen is an ideal, non-polluting and carbon neutral fuel.

Electromaterials can inherently store charge within their structure, and optimising the nanostructure of these electrodes and electrolytes for use in fuel cells can dramatically improve the performance of these devices.

Researchers at the Materials node of ANFF are developing electrode materials for water splitting. These electrodes are the most critical component of the fuel cell as they are responsible for splitting the H_2O (water) such that the H_2 (hydrogen) fuel can be captured. A focus of their research is to understand the key parameters, including nano-structure and composition, and identify the electromaterials that most efficiently split water.

Using ANFF facilities and expertise a number of materials are to be fabricated into electrodes with these key electromaterial properties. These will then be tested to identify the best water splitter, which will then be incorporated into the design of the new solar hydrogen fuel cell.

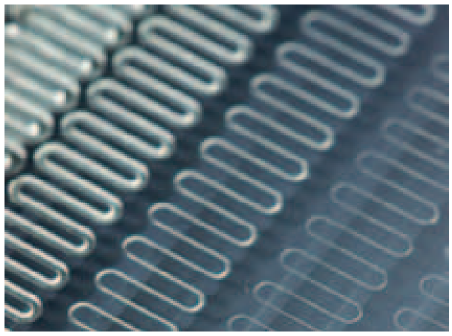
A key goal for the advancement of this technology is the demonstration of a manufacturable practical device.

MICRO-EXTRACTION FOR INDUSTRY

Craig Priest, South Australian node - University of South Australia

The lab-on-a-chip is revolutionising the way small volume samples are handled in chemistry and biology, however microfluidic process intensification may pave the way for advanced manufacturing at more industrially-relevant scales.

Dr Craig Priest (ANFF-SA) is investigating the use of microchannels to efficiently extract metals from mineral processing streams which cannot be processed using conventional methods. Micro-solvent extraction relies on the high surface-to-volume ratios and precise control of micro-scale fluid phases. The technology was inspired by the pressing need to make the energy, resource, and environmental footprints of industry smaller without losses in process efficiency.



Microfluidic device.
Credit: SA node, University of South Australia

ENHANCING THE PERFORMANCE OF SILICON SOLAR CELLS

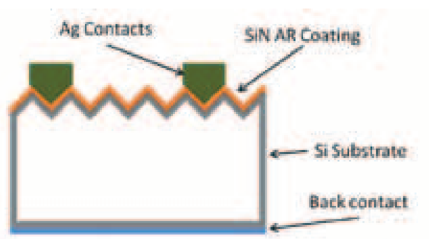
Narges Fahim, Baohua Jia and Sasi Kandasamy, Victorian node - MCN

ANFF is supporting research developing coatings for solar cells that allow them to capture more energy by reflecting less light.

The technological challenge at the Melbourne Centre for Nanofabrication, and the Centre for Micro-Photonics at Swinburne University of Technology was to provide a reliable and reproducible technique where superior control of thin film properties (thickness and refractive index) was possible.

A high quality anti-reflective coating (ARC) is vital for solar cell performance as it ensures a high photocurrent by maximizing light absorption. The plasma-enhanced chemical-vapour deposition (PECVD) method is a proven technique for obtaining layers that meet the needs of surface passivation and antireflective coatings.

The MCN, in collaboration with the Centre for Micro-Photonics, has progressed to a stage in the project where the deposition parameters for the SiN layer have been characterised to provide a refractive index of 2.05, which is optimal for antireflection properties. The next phase is planned for testing of these devices to verify the enhancement in the performance of the solar cell due to the addition of the SiN anti-reflective coating. A schematic diagram of a Si based solar cell with SiN anti-reflective coating along with a fabricated Si solar cell is shown in figure above.



Basic structure of a silicon based solar cell with SiN anti-reflective coating using PECVD technique

Credit, Victorian node, Swinburne University of Technology

SILICON CARBIDE, THE GREEN SEMICONDUCTOR

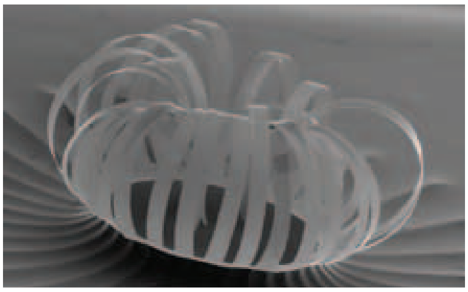
Dr Francesca Iacopi, ANFF-Q - Griffith University

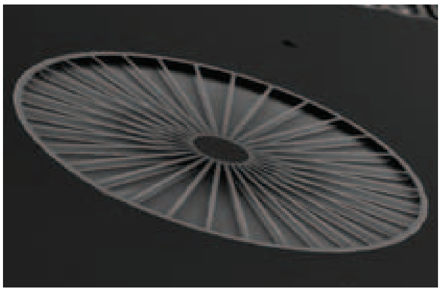
Is silicon carbide the new "green" silicon? Ask ANFF-Q's newest Future Fellow, Dr Francesca Iacopi. "In the next decade silicon carbide (SiC), and other wide bandgap materials, will unlock technology behind a vast range of energy efficient smart devices" said Francesca.

"These devices will increase the efficiency of photovoltaic panels, hybrid/electric cars, high-power industrial drives, motor drives, smart grids and power utilities, improving energy efficiency and lessening our carbon footprint. There's also potential for accelerometers and gyroscopes for aerospace and automotive uses, as well as in the harsh environments of mining and deep sea exploration" she adds.

The key behind SiC's advantages are its thermal and electrical properties allowing it to remain stable at high temperature and in harsh environments. Adopting SiC semiconductor devices will allow a higher electric current to pass through a device while eliminating the need for heat sinks and other cooling systems.

Frost & Sullivan*, a US based authority in market research, agree. They report that SiC-based power electronics are well positioned to meet some of the key performance criteria, such as decreased overall system costs and enhanced system efficiency, for emerging applications in the renewable energy, utilities and industrial sectors.





Micro-electro-mechanical devices (MEMS) made from SiC-on-silicon at the ANFF-Q. Griffith University. Credit: Queensland node, Griffith University

To date, SiC has not grabbed much attention in the semiconductor world due to the high cost of its production and fabrication in bulk or wafer form. The group at Griffith hold the solution to this problem with both their experience in SiC-on-silicon technology and ANFF facilities.

The technology captures all of the advantages of SiC while only using a very thin film of the semiconductor. This film can be grown in-house with their recent installation of a SiC epitaxial reactor, one of ANFF's flagship facilities and the only one of its kind in Australia. It can dramatically reduce production costs and also reach out to a much broader spectrum of applications.

The significance of SiC-on-silicon technology development has been recognised as a 21st century challenge by the ANFF and the Australian Government. The Australian Government has awarded Francesca a prestigious Future Fellowship that will provide over $700,000 for her to develop new green applications for SiC and wide bandgap materials. The ANFF has strategically supported the existing expertise in SiC-on-silicon technology at Griffith by installing the SiC reactor using an investment from the Education Infrastructure Fund.

ANFF would like to congratulate Francesca on receiving the Fellowship and in her endeavours in keeping Australia at the forefront of this revolution in semiconductor technology. ANFF hopes that future investments in both infrastructure and personnel will keep Australia as leaders in this and many other fields of nanotechnology.

*Frost and Sullivan: Silicon Carbide Electronics —Technology Market Penetration and Roadmapping.

MANUFACTURING EFFICIENT SOLAR CELLS

ACT node - Australian National University

Increasing the efficiency of solar cells and reducing their manufacturing costs are key challenges in making their use economically viable.

When sunlight strikes a solar cell, the incident energy is converted directly into electricity by the photovoltaic effect without creating harmful pollution. Photovoltaic solar energy is one of the fastest growing renewable energy technologies in the battle to mitigate climate change.

Researchers at the Australian National University have found a means to fabricate a solar cell that allows more electrons to be captured to create a higher electrical current and a more efficient device. However, a critical step in this process is the "atomic layer deposition" (ALD) of an Al_2O_3 passivation film. This process remains a challenge for the industry as it is not a high throughput process. Using facilities at the ACT node of ANFF, a new fabrication process based on reactive sputtering using an Al target + O_2 has been developed instead. This is significantly easier than ALD and is a promising alternative for depositing the dielectric layer in commercial quantities.

3D ROCK ANALYSIS HELPING THE MINING BOOM

Digitalcore, ACT node - Australian National University

The ability to rapidly and efficiently analyse core samples for prospective oil and gas exploration operations using micro and nanotechnology is enabling more effective extraction of hydrocarbons.

Digitalcore has won the prestigious 2012 Eureka Prize for Commercialisation of Innovation for its efforts bringing this technology to the mining industry.

Digitalcore, a long time client of the ANFF ACT node, provides 3-dimensional analysis of core samples, primarily using X-ray CT scanning. For some samples, CT scanning does not have the resolution to see the nano-scale features required for a meaningful analysis.

Using the Focused Ion Beam (FIB) system and expert staff at the ACT node, Digitalcore has developed a 3D imaging technique for minerals with such fine features.

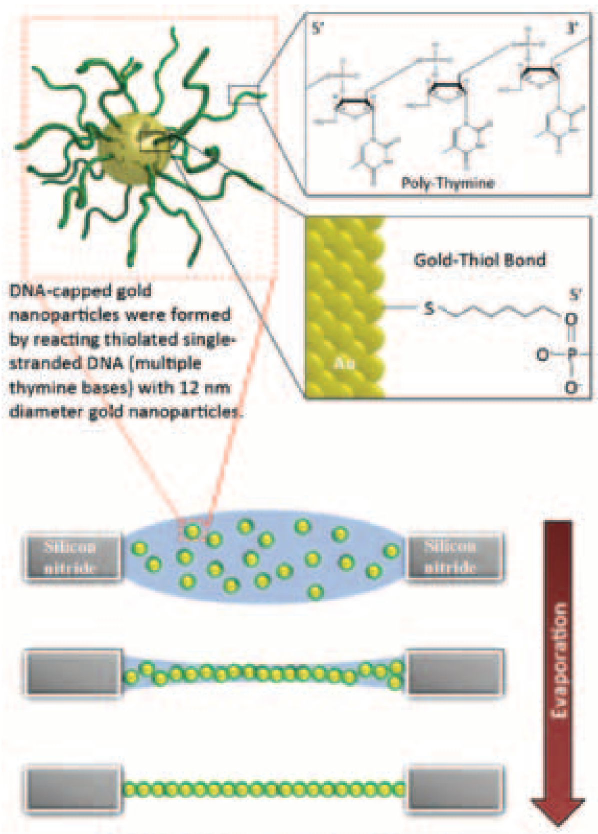
The technique uses a focussed gallium ion beam to mill a small hole in the sample. Using the scanning electron beam integrated into the FIB system, the edge of this hole can be imaged. Images of subsequent slices milled from the edge of this hole can be combined to create a single 3D image with nanometre resolution.

"Together with ANFF, we have been leading the application of these (FIB) systems on rock samples to produce nanoscale 3D images of tight unconventional geological systems such as shales and tight gas" said Dr Victor Pantano, CEO of Digitalcore.

"This work is important as these geological samples cannot be analysed using traditional means, and thus the work with the ANFF provides a means of characterising these increasingly important oil and gas bearing formations."

SMART MEMBRANES

Wenlong Cheng, Victorian node - Monash University & MCN



Drying of a microconfined droplet of DNA-capped nanoparticles leads to the formation of the thinnest possible free-standing nanoparticle superlattice membranes. Credit: Victorian node, Monash University

The development of smart, ultrathin, multifunctional nanobio membranes will lead to the improved technologies in seawater desalination with low energy consumption, and at-home, lightweight and highly sensitive foldable toxic gas detectors. MCN technology fellow, Dr Wenlong Cheng from Monash University is tackling the problem of developing intelligent, ultra thin nanobio membranes for applications in environmental monitoring.

The project requires combined top-down lithography (photolithography) and bottom-up self-assembly (DNA-programmable materials synthesis). The facilities at MCN are important for this work because there are state-of-the-art lithographical tools (photolithography, e-beam lithography, focused-ion-beam lithography, etc.), characterisation tools (AFM, SEM, confocal microscope, etc.), and biological labs.

The University of Adelaide Australia

ANU

Bandwidth Foundry

CSIRO

Deakin University

Flinders University

Griffith University

La Trobe University

Macquarie University

The University of Melbourne

Monash University

The University of Newcastle Australia

UNSW Australia

The University of Queensland Australia

RMIT University

UniSA

Swinburne University of Technology

The University of Sydney

University of Technology Sydney

The University of Western Australia

University of Wollongong

An Australian Government Initiative
National Collaborative Research Infrastructure Strategy

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Victoria The Place To Be

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