ANFF

Australian National Fabrication Facility

The home of tomorrow's entrepreneurs

2015

CASEBOOK

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ANFF – The home of tomorrow's entrepreneurs

In 2007, ANFF was established to provide facilities that were not otherwise available in Australia, and to support areas of micro and nano fabrication research in which Australia excelled.

The uptake by both university and industry researchers has been significant, growing consistently from less than 30,000 hours of tool usage in 2008/09 to over 190,000 during 2014/15.

It is not only the quantity of research that has increased, but also the profile. Last year more than 50% of the academic publications generated with the support of ANFF were featured in the top-rated 5% of academic journals.

The benefit that ANFF provides has been noticed on an international stage. Usage by international researchers has also increased significantly, with collaborative projects under development with organisations such as the US Air Force and NASA.

While it could be argued that these impacts for Australia were anticipated as part of the original strategy for NCRIS and ANFF, there are a number of other opportunities that were not.

This year we're focusing on the innovative research carried out in the facilities around Australia and ANFF's role in supporting entrepreneurs.

Entrepreneurs play a key role in a country's economy and must be equipped with the skills to take new ideas to market. ANFF fosters entrepreneurship by training researchers in the micro and nano fabrication skills necessary to fabricate devices and advanced materials.

ANFF enables researchers to develop new ideas that have long-term implications, and provides the facility to take publicly funded research along the pathway to creating commercial outcomes that will ensure the competitiveness of the Australian economy in the future.

This casebook, *ANFF – The Home of Tomorrow's Entrepreneurs*, tells some of the stories of today's entrepreneurs from the ANFF Network who are bringing their technologies to market, including some of the seven start-up companies that have emerged from ANFF nodes.

While ANFF will continue to support these micro and nanotechnology entrepreneurs in the years to come, it is recognised that their innovations are the product of many years of fundamental high-profile research.

This year's casebook is the biggest we have published to date, with 36 case studies: a reflection of the number of opportunities for Tomorrow's Entrepreneurs to establish new industries in Australia. These case studies span all of the nine national research priorities set out by the Australian Government.

This casebook also includes feedback from our roadshow *ANFF 2025 – Future Capabilities Consultation*, which ran earlier this year. The sessions provided an opportunity for ANFF to identify the challenges that the nanotechnology research community is seeking to tackle in the next seven to ten years. Key findings from the consultation will help to identify the research infrastructure and capability that ANFF needs to offer going forward, and prepare us to best support this community over the coming decade.

By providing this support, ANFF can maintain the flow of new opportunities for the nanotechnology industries of tomorrow.

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An Australian Government Initiative

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Cover image credit: Paul Henderson-Kelly.

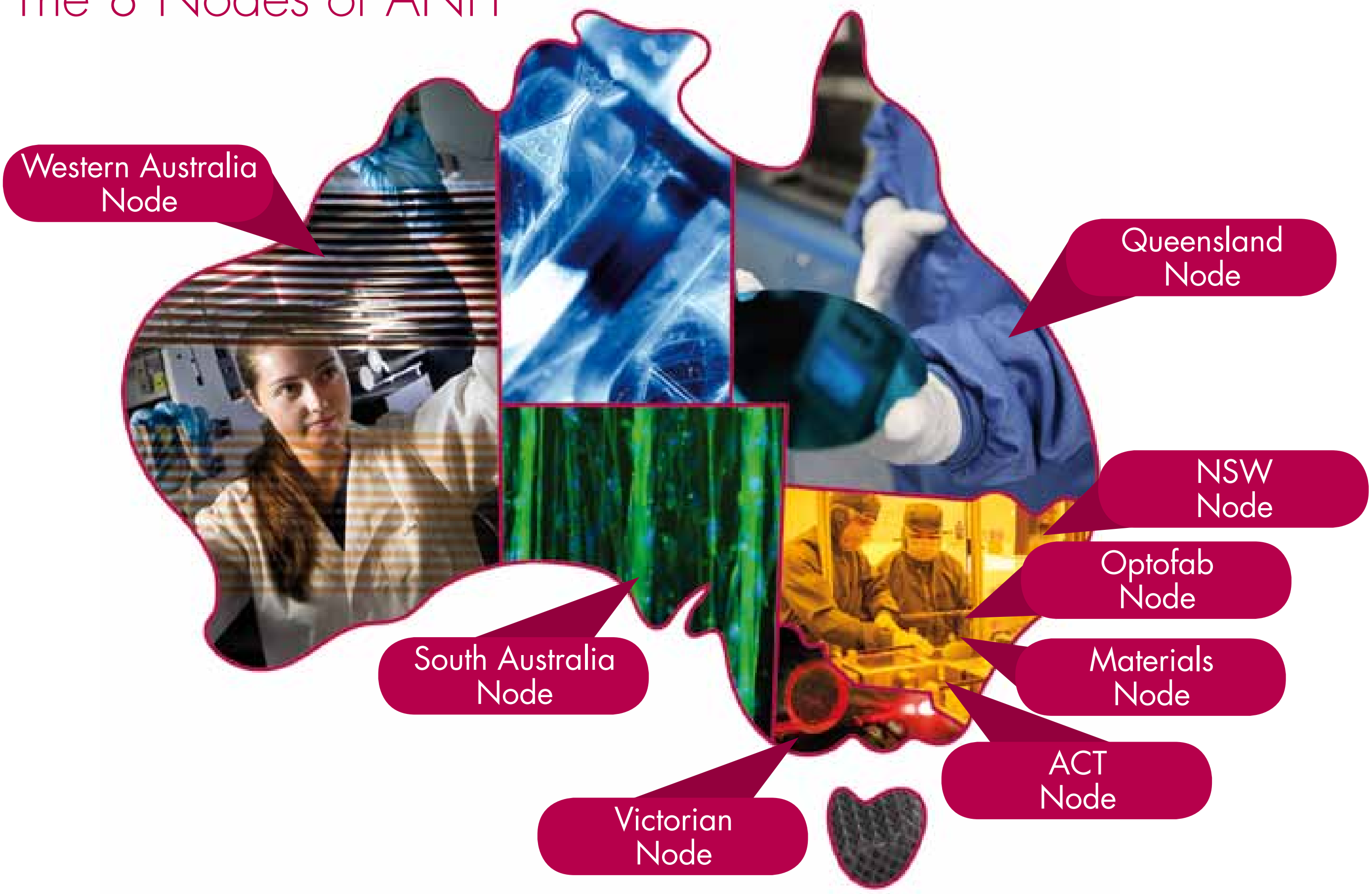
Snapshot of ANFF

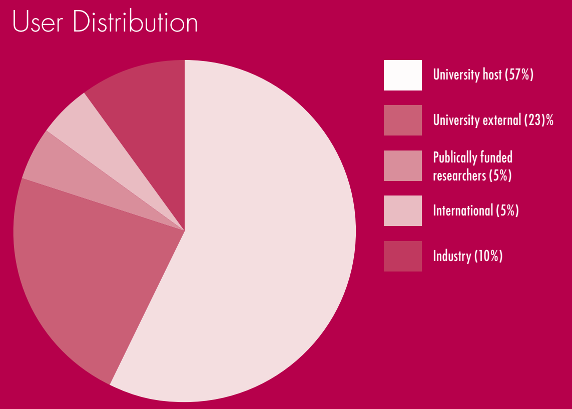
ANFF was established under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS).

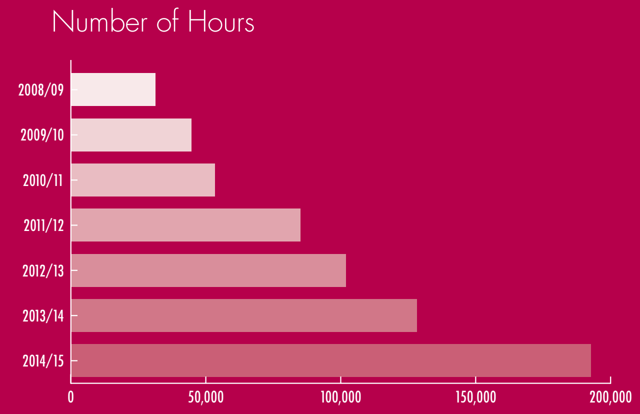
ANFF's mission is to provide micro and nano fabrication facilities for Australia's researchers, SMEs and start-up companies.

Over 500 facilities are located across 21 institutions around Australia in a national network of 8 nodes. Each node offers complementary specialised manufacturing facilities supported by trained staff.

The 8 Nodes of ANFF







Supporting Australian researchers in 2014/2015

Providing access to micro and nano fabrication facilities

ANFF facility usage increased by 50% relative to 2013/2014.

192,639 hours of ANFF facility time was consumed by 2,672 researchers fabricating new devices, novel materials and prototypes during 2014/15.

Critically, this activity delivers world class research, attracts international collaborators, and builds support for entrepreneurs who want to contribute to Australian industries or start new ones.

Supporting world class research

More than 50% of ANFF related publications were featured in the top rated 5% of international journals as ranked by ERA.

Inspiring collaboration

International usage of ANFF facilities increased by 40% in 2014/15. Over 9,000 tool hours were used by international research collaborators.

Supporting tomorrow's entrepreneurs

ANFF usage by companies grew 35% during FY14/15.

Almost one third of the 16,500 industry hours were from international entrepreneurs and companies using ANFF facilities for their R&D.

• *Delegates at the Enabling Technologies workshop, Arlington, VA 2015.*

Earlier this year, we ran *ANFF 2025 – Future Capabilities Consultation*. This was a chance for the fabrication community to get together and talk about the research challenges that we're seeking to tackle in the next seven to ten years. In February and March 2015, events were held in six cities across Australia. Based on the Australian Academy of Science's 'National Nanotechnology Strategy 2012', we considered four different thematic areas: photonics, nanobio, advanced materials, and nanoelectronics. Key findings from the consultation, which are outlined on the following pages, will contribute to identifying the research infrastructure capability that ANFF needs to offer going forward.

ANFF 2025

Future Capabilities Consultation

Photonics represents 10% of the economies of the US and Europe.

Photonics

Australian advances in photonics have the potential to create impact in fields as diverse as neuroscience and astronomy. But unless researchers can take fully packaged devices or working prototypes directly into their laboratory we won't achieve cross-discipline take-up. For a fibre sensor to be used by a biologist, it must be packaged ready for connection to the biological system under test. It might also be necessary to use softer materials rather than a rigid case to match the mechanical properties of the electrodes to the environment, which might be bone or soft tissue.

From under the earth to the stars above, vertical integration is essential for the deployment of photonic technologies. A 3D photonic chip is at the heart of the *Dragonfly* interferometric instrument for detecting extra-solar planets. The chip, made by the ANFF Optofab node, has been demonstrated 'on-sky' at the Anglo Australian Telescope at Sliding Spring NSW. The node is now working with Sydney Water to develop a fibre-based system for monitoring the network of underground water pipes for concrete corrosion. Devices must be robust and able to function for long periods in dirty environments.

The incremental advances of a photonics roadmap have the potential to underpin groundbreaking advances in other disciplines, such as biophotonics. ANFF must provide the integration, packaging capabilities and skilled personnel to make this happen.

World leaders in photovoltaic technologies, Australian researchers must be able to fabricate large-area solar cells to work with international industry and secure investor engagement. This requires large area deposition facilities. Current research by CSIRO supported by ANFF-Vic includes plasmonic enhanced solar cells with improved light harvesting, and thermal management systems for improved conversion efficiency.

Challenges facing Australian researchers include reproducibility for commercialisation of devices and the ability to demonstrate nanoscale functionality across large wafers.

Optical fibre fabrication is being applied to new types of materials, combining optical and electrical arrays, which offer the potential to detect neural signals in vivo. Limited by the fibre drawing process to certain structures, 2D photon polymerisation might hold the pathway to new geometries.

Research opportunities exist at the interfaces. As well as vertical integration, interfacing photonics with electronics and fluids creates the potential for smaller, faster and lighter devices. Disruptive technologies include the use of photonic integrated circuits as a scalable platform for complex quantum systems. Integration of single-photon detectors and light sources on a chip to reduce optical losses creates a base for the implementation of advanced sensor systems. Microfluidic devices have been described as a 'lab-on-a-chip' suitable for point-of-care diagnostics, but coupling to the device is a challenge.

Technical challenges include materials compatibility, bio-functionalised surface engineering and the ability to access international foundries, which is limited for material systems other than silicon. Australian research in niche areas including hybrid chips with III-V materials and silicon cannot be easily undertaken at an international foundry due to contamination issues. Solving challenges overseas also means losing a degree of insight into the process. We need to be internationally aligned and take care to avoid non-compatibility, but we also need an Australian capability as a bridge to foundry manufacturing.

To enable photonics research we must understand the end-user needs, from one-off demonstrations to medical trials, together with the applicable standards for industries including defence, biomedical and telecommunications.

Nanobio

Nanobio research supported by ANFF has enabled the development of biosensors and diagnostics for early disease detection, health monitoring and treatment. Areas of intensive research and development include engineered scaffolds for regenerative medicine and intelligent delivery systems for genetic material, drugs and vaccines. Australia's reputation in medical technologies is highly dependent on being at the forefront of nanobio and fabrication technologies that enable implementation.

The translation of research requires production of sufficient quantities of materials and devices for development and clinical trials. With our current strategies ANFF has enabled companies such as Vaxxas to progress towards market with the Nanopatch™ and enabled clinicians with improved product ideas, such as new glaucoma implants, to realise designs resulting from decades of knowledge in just a matter of days. ANFF is establishing hospital-based facilities to ensure more returns like this.

Since the establishment of ANFF, researchers have used the facilities to print a multitude of materials, including bioactive components (proteins, drugs and cells), polymers, metals and inorganics to fabricate structures and devices containing nanocomponents. This has required the development of new tools and techniques. These new printing protocols and the customised machinery used to implement them keep Australia ahead of the game.

Future research challenges include the fabrication of 3D structures containing living cells for testing of drugs and other therapies. This will bring clinical treatments closer to fruition and enable fundamental research into cell and developmental biology together with the molecular pathways in cells that regulate tissue morphogenesis and disease. To create these structures, multi-dimensional fabrication involving both hard and soft materials is needed. To print a kidney for drug screening, for example, would require more than 26 different types of cells across different length scales. Multi-compositional fabrication involves controlling the spatial and temporal delivery of multiple cell types with multiple materials. High speed, high resolution printing in the clinic, together with appropriate characterisation techniques, requires continuing development.

In addition to healthcare, new areas of work include food science; in particular, understanding the gut mechanical model and the implications for food formulation and processing, agriculture and water.

The demand for nanomaterials is forecast to grow by > 30% annually to 2020.

Advanced materials

New materials-based markets and technologies are emerging and Australian participation will be critical in the transitioning global economy. While the term nanomaterials is widely used, we are focused on those materials that exhibit a change in their properties (for example, optical or electrical) as their size approaches 100 nm and smaller. Opening markets for nanomaterials in renewable energy, electronics, personal care products, medicines, nano-composite building materials, and advanced coatings will depend on meeting a major challenge: bridging the gap between the scientific understanding of new materials and scaled and standardised manufacturing.

Leading edge research now includes time resolved studies; for example, of microfluidic movement and novel materials such as graphene, to overcome the limitations of Moore's law. New advances in biophotonics – exploiting engineered biomarkers and bioactive nanomaterials – in combination with leading 'lab-on-a-chip' modules is revolutionising point-of-care diagnosis and personalised medicine.

The design and functionality of nanomaterials is tuneable for specific applications in potentially lucrative markets such as energy production and storage, medicine, and new device technologies. Scale-up of manufacturing will vary greatly between materials and applications. Transitioning from laboratory to commercial quantities might mean batches of as little as one gram or as much as one tonne, depending on the material and market needs.

The rapid growth in scientific insight has not been matched by standardisation in the production and characterisation of materials. Challenges include controlling the shape and properties of nanoparticles to produce narrow size distributions, but the repeatability of materials synthesis and measurement is low. Batch inconsistencies can lead to variable material performance. Problems include variation in the raw materials; for example, the raw materials sourced from glass companies for the production of speciality glasses for photonics applications contain varying amounts of impurities. For 'bottom-up' syntheses continuous-flow production methods are desirable, for example in microfluidic and/or flow

chemistry unit operations. 'Top-down' production of nanoscale features can be scaled up by using large wafer platforms or drawing towers (fibres) in 'pre-foundry' facilities.

In some cases, the shelf life of fabricated materials is not sufficient. Quality assurance, including purity, size, and shape of individual particles/ structures, and the collective function of complex assemblies, will be required for end-user confidence in nanomaterial technologies.

Complex nanosystems – beyond 'simple' particles – will be increasingly important, requiring the development of new techniques for manipulation and self-assembly of particles and materials. Nanomaterials that interact with one another to 'cooperate' at the nanoscale will impact advanced optical, electrical, mechanical, and biological use.

The interface between the nano, micro, and macro world is difficult to bridge. Advances in the fabrication of different nanoparticles and nanomaterials must now be complemented by integration of these materials into devices. NV (nitrogen vacancy) centres in diamond are an example of a nanomaterial and can be used for single photon generation. Application of this technology requires complex and precise integration with micro and macro device components. Similarly, the improved efficiency of III-V nanowires for light harvesting must be coupled with silicon to create optical devices and nanochannels must be connected to microchannels for fluid applications, which are in turn connected to mm-scale fluid ports and tubing.

Extending the activities of the ANFF Design House and the need for computational materials design has also been recognised.

Nanoelectronics and nanomagnetics

Nanoelectronics and nanomagnetics involve the study of phenomena or functional properties that depend on electron charge and/or spin constrained to the nanoscale. Australia's research strengths in this field include quantum science and quantum technologies, microelectromechanical systems (MEMS) technology, plasmonics, and nanomagnetics. In common with other themes, challenges for this area include integration, packaging and scaling.

In October 2015, researchers at ANFF-NSW reported the fabrication of a quantum logic gate in silicon in the journal *Nature**. Applications of quantum computing include finance, security and healthcare; for example, allowing the identification of new medicines by greatly accelerating drug design. While the UNSW group have patented a design for a full scale quantum computer chip that would allow scaling to millions of qubits, the next steps towards a device with tens then hundreds of qubits require greater reliability and more stringent engineering controls than those currently achieved in university-based cleanrooms. This requires a major investment in infrastructure if the work is to be undertaken in Australia. Improved engineering controls would help to extend the lifetime of current nanoelectronics devices, which are often limited by oxidation and contamination, with performance degradation occurring after just six months.

MEMS devices, integrating microscale mechanical or movable parts with electronic circuits, are being used to fabricate sensing devices that duplicate human senses to 'see', 'hear', 'smell', 'taste', or 'touch'. MEMS-based wavelength tuneable infrared miniature spectrometers are bringing colour vision to infrared sensing, while monitoring of MEMS nanomechanical motion affected by preferential adsorption of predefined biological or chemical agents is allowing devices to 'smell' and 'taste'. These new sensing modalities are expected to disruptively impact the already firmly established global dominance of MEMS in sensing technologies commonly found in smartphone, automotive, aerospace, and military applications.

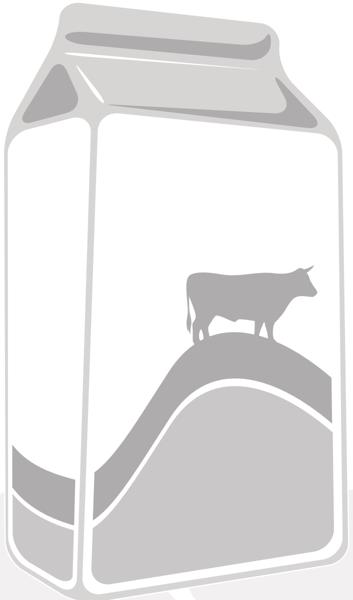
The integration of hybrid materials will be crucial in the advancement of a number of technology areas. For example free-space optical communications will require interfacing between photonics and nanoelectronics. Nanowires provide a pathway for integration of hybrid III-V materials on silicon because the 3D structure of the nanowires overcomes the lattice mismatch in 2D planar devices. Interfacing nanoelectronics with life sciences applications; for example, using silicon-based devices for cell sensing and readout, requires that the devices be bio-compatible. Due to the toxicity of some components, the challenge is to encapsulate the devices.

New and hybrid materials will allow developments in a number of areas. Approaches to tackling the limits of Moore's Law include new 2D materials in addition to graphene; for example, molybdenum sulphide. The rare capability to fabricate mercury telluride-based structures has allowed Australian researchers to develop topological insulators, which represent a disruptive technology for next generation electronics. Future areas of research include plasmonics – with applications in light harvesting and optical circuits – and metamaterials.

** Veldhorst, M. et al. A two-qubit logic gate in silicon. Nature 526, 410-414, doi:10.1038/ nature15263 (2015).*

FOOD

Australia boasts well developed agriculture and fishery industries, but continued innovation is needed to ensure that food is produced efficiently, sustainably and plentifully enough to service local and global markets. Researchers at ANFF nodes around the country are contributing to this challenge with novel technologies that can be seamlessly integrated into the food production chain.



MOO JUICE:

detecting milk spoilage enzymes in minutes

Dairy products are a staple in the diets of millions of people around the world. Australian milk production is constantly growing, with the local industry producing over 9.2 billion litres during the 2013/2014 financial year and exporting nearly half of that.

However, the efficiency of milk production leaves much to be desired. Throughout the production process, samples spend hours or even days being tested for contaminants and spoilage enzymes to ensure the milk is safe for consumption. These delays result in significant loss of time and resources, as well a shortened lifespan of the final product; a serious problem in the context of Australia's status as a geographically isolated exporter of products.

New biosensing devices developed in partnership with the ANFF-SA node provide a potential solution to these issues, enabling real-time detection of spoilage enzymes in dairy products. The research team, led by Murat Gel from the CSIRO, used multilayer glass bonding technology to fabricate microfluidic devices featuring inlets for the introduction of the milk sample and the biosensor. These reagents mix within the device and provide an optical result. Rapid biosensing performance was successfully achieved in the prototype device.

Following the success of this project, fabrication will now commence for devices that can be used on raw milk in milk processing plants, minimising the testing stage and dramatically improving the productivity of the Australian dairy industry.

It is envisaged that this technology will be used throughout the entire milk production chain, from farmers to transport drivers to dairy product producers.

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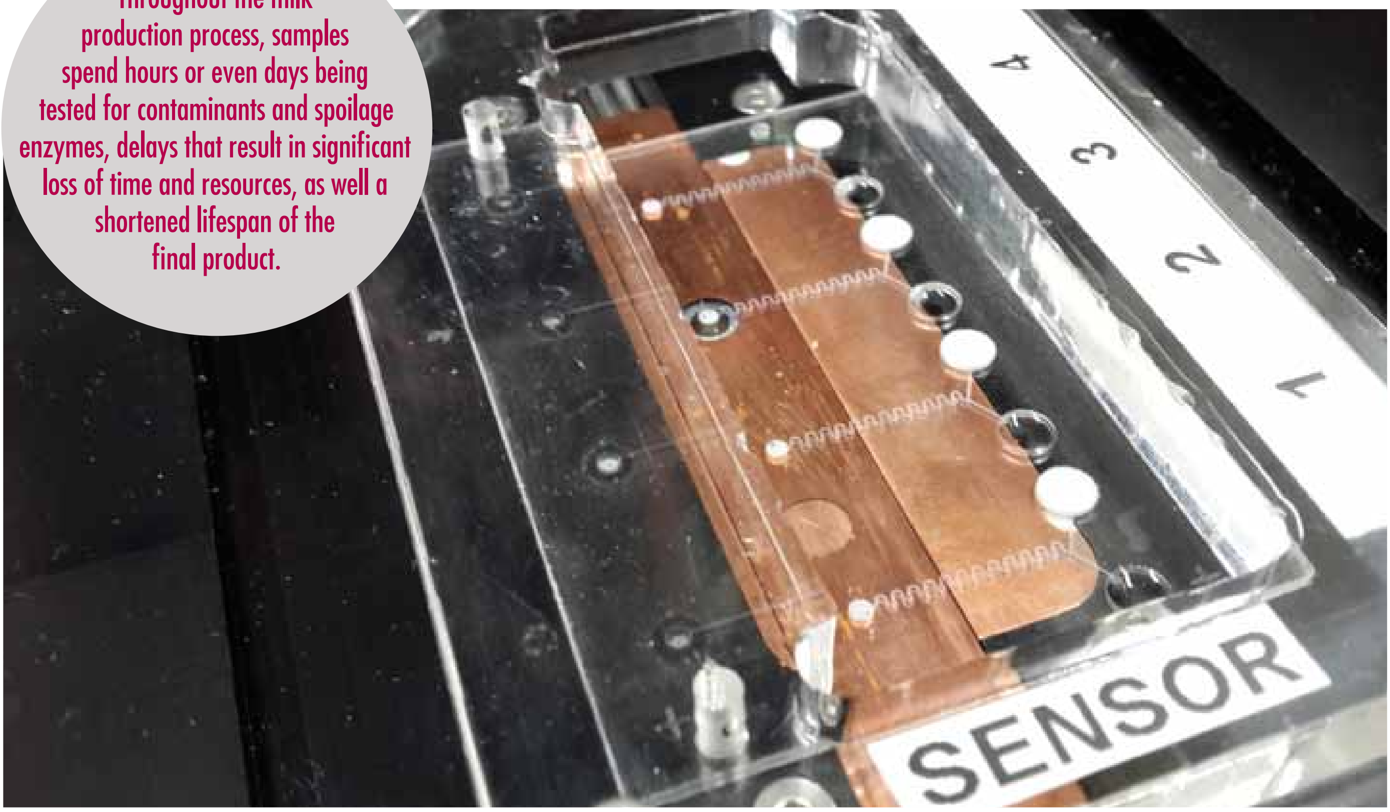

• *Fabricated chip in operation during real-time detection of spoilage enzymes in milk samples.*
Credit: CSIRO, Manufacturing Flagship, Food and Nutrition Flagship.

DESIGNING TOMORROW'S super foods

You've no doubt been told time and time again to eat plenty of fibre. But what happens inside the body when you do? Researchers at the Australian Research Council Centre of Excellence in Plant Cell Walls are investigating how plant cell walls respond to mechanical stress and how cellulose – the central component of plant cell walls – harbours beneficial dietary fibres and enhances their performance inside the body.

Dietary fibre performs two major functions. In the small intestine it slows digestion of macronutrients such as starch, protein and fats. In the case of starch, it helps to smooth out the blood glucose levels that would otherwise spike after a meal and cause stress to the insulin system. In the large intestine, dietary fibre helps to maintain the healthy balance of bacteria necessary to keep the body hydrated and support the immune system.

The perfect whole-food diet needs to fall within the 'Goldilocks zone' of cell wall breakdown. If we consume cell walls that are too tough (for example, undercooked legumes), many beneficial nutrients bypass our digestive system and are instead released by bacteria in the lower segments of the gastrointestinal tract – causing gas and discomfort. On the other hand, if walls are too soft, their rapid breakdown can lead to undesirable surges in blood lipids and glucose.

Determining the mechanical properties of plant cell walls can provide important information about how the cell walls will break down inside the body. The research team used the Atomic Force Microscopy (AFM) facilities at ANFF Queensland (ANFF-Q) to develop two new techniques for assessing these properties: the multi-regime nanoindentation analysis technique and the 'dip and drag' AFM technique.

The multi-regime nanoindentation analysis allows researchers to probe cell wall deformations at different scales, gather structural information, and identify weak and tough spots within the wall. Indeed, the failure of the wall may be due to the presence of such weak spots rather than the overall toughness of the wall. The 'dip and drag' AFM technique gives information about the interactive forces between cellulose fibres, which tells researchers how the chemistry of different wall components may impact the strength of the links and therefore determine the toughness of the wall.

These techniques will pave the way for future studies on food systems aimed at understanding the relationship between cell wall composition and microstructure, which ultimately determines the fate of foods within the digestive system. The team aims to uncover the key design rules that will enable the development of foods – both through food processing technologies and through agricultural means – with optimum breakdown patterns. Ultimately, this will promote healthier dietary choices and enhance the nutritional value of common foods.

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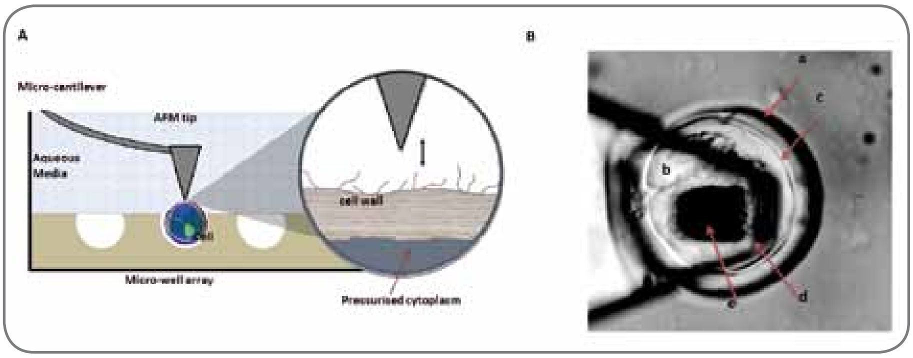
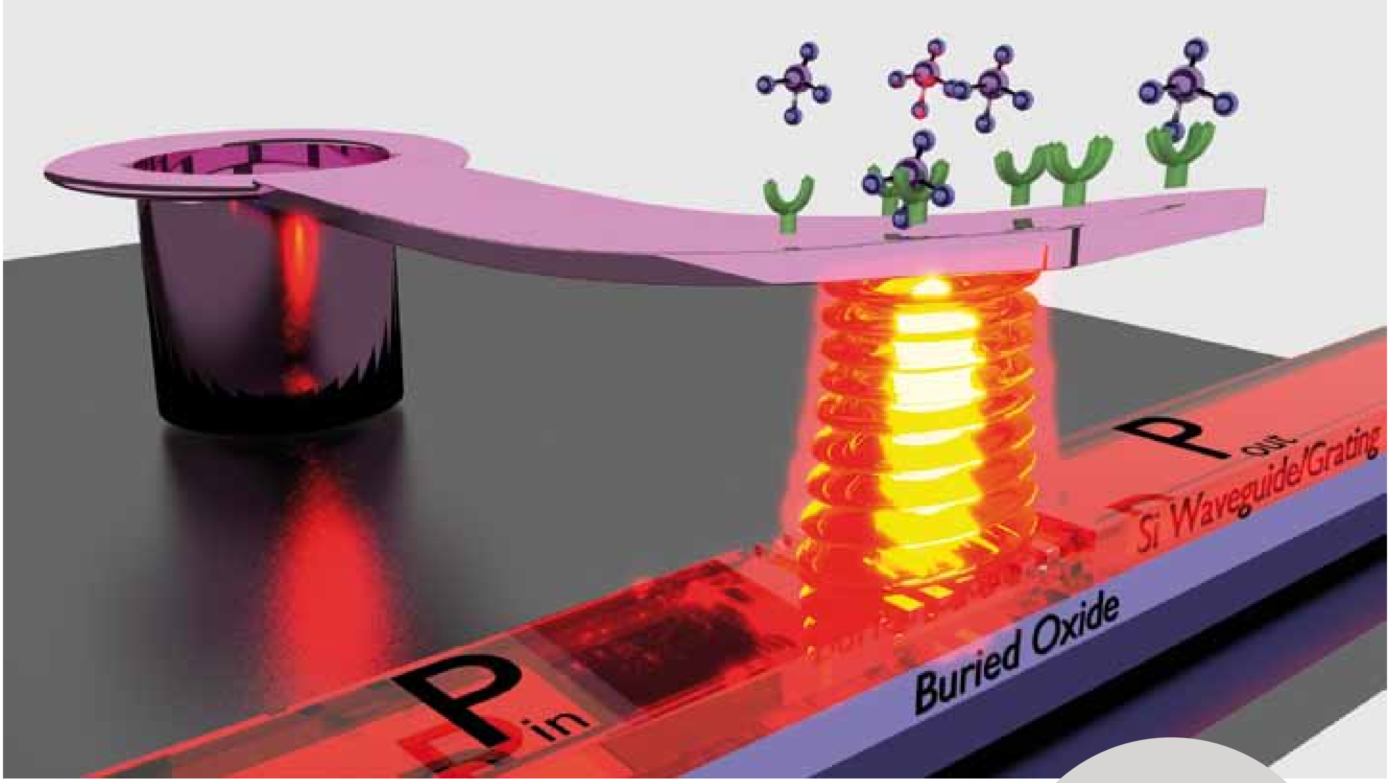


• *(A) – Schematic diagram of indentation experiments using Lolium multiflorum cells confined within PDMS microwells. The zoomed-in sketch represents the complex layered structure of the cell surface, where the multi-regime nature of the elastic response originates.*
(B) – A dual illumination (bright-field and reflected light) optical micrograph of a L. multiflorum cell (b) confined within a PDMS micro-well (a). An AFM cantilever (d) is positioned above the cell so that the tip (e) is positioned approximately above the apex of the cell. The cell wall (c) can be clearly visualised as a shell surrounding the cell. Credit: Dr Gleb Yakubov.



• *Schematic of the LumiMEMS structure: a MEMS cantilever that bends when chemicals are absorbed. The laser light beneath the cantilever measures the bending.* Credit: Dr Gino Putrino.

A device to 'sniff out' rotting groceries

The project uses chemical sensors to develop miniaturised devices that will give people important information about their environment.

Imagine this: you're at the supermarket doing your weekly grocery shop. Wandering through the produce section, you spot the tomatoes and grab a bag. As you're putting the tomatoes into your trolley, you notice some brown spots. Simple discolouration or something more sinister? What if there were a device that could tell you, with a click of a button, whether your spotty tomatoes are emitting any signs of internal rot?

Devices like this will soon be real thanks to research from the University of Western Australia (in the ANFF-WA node) that is now being commercialised by Panorama Sydney Pty Ltd.

Initiated by Prof. John Dell under an ARC Discovery Project, and developed further by Dr Gino Putrino and his research team, the project uses chemical sensors based on microelectromechanical systems (MEMS) cantilevers to develop miniaturised devices that will give people important information about their environment.

MEMS cantilevers can be thought of as incredibly tiny diving boards, which bend as they absorb specific chemicals. However, the process happens on a microscopic scale that is impossible for the naked eye to detect, which makes it difficult to adapt for a functional chemical sensor.

To tackle this problem, the research team incorporated laser light paths within a silicon chip, and used surface micromachining techniques (depositing layer after layer of thin film until the desired shape is achieved) to build MEMS cantilevers above those light paths, allowing the lasers to detect those subtle movements of the cantilevers that the human eye alone cannot.

Integrating this process into the chip allows simultaneous monitoring of many cantilevers within a small, handheld device. Different applications can be achieved by using different 'functionalisation' coatings, which preferentially absorb the chemical the device is intended to detect. Applications for this technology range from sensing rotting groceries, to point-of-care medical sensors, to detection of toxic gases.

This new technique, dubbed LumiMEMS, is capable of measuring the MEMS movements to a degree of pico-meter accuracy previously only achieved using large and bulky benchtop instruments. Integrating the lasers into the chip itself not only achieves results on a smaller scale, but also eliminates any interference caused by external vibrations.

Panorama Synergy Pty Ltd joined the LumiMEMS project following proof of concept. Test devices are currently being designed and fabricated for a number of applications.

SOIL & WATER

Making up the base that our society is literally built upon, Australia's soil, vegetation, biodiversity and water are incredibly valuable yet poorly understood resources. Technologies developed at ANFF improve our ability to observe and monitor these systems, and more accurately predict change.

From molecules to minerals:

understanding the mineral formation process

In everyday life we are surrounded by the crystalline structures known as minerals. Despite their importance, the process by which minerals form is poorly understood.

Calcium carbonate minerals, for example, are the building blocks of coral reefs, a component in the manufacture of cement, and are also used as an acidity regulator in food.

Understanding how molecules arrange themselves into minerals would provide exciting new opportunities to understand the chemistry of a huge range of environmentally, biologically, and industrially significant processes.

However, it is very technically challenging to observe and measure the first stages of mineral formation due to their scale; many of the steps take place within less than a thousandth of a second, and just a few nanometres.

Researcher Dr Luke Parkinson at ANFF-SA, in collaboration with Dr Andrew Rose of Southern Cross University, has recently constructed microfluidic devices that can control the conditions under which mineral formation occurs.

The devices enable researchers to mix two reagents (in the form of thick streams of liquid), which enter the device through separate channels. The inner walls and channels of the device split the streams into much thinner streams, which then wrap around each other to form a single thick stream.

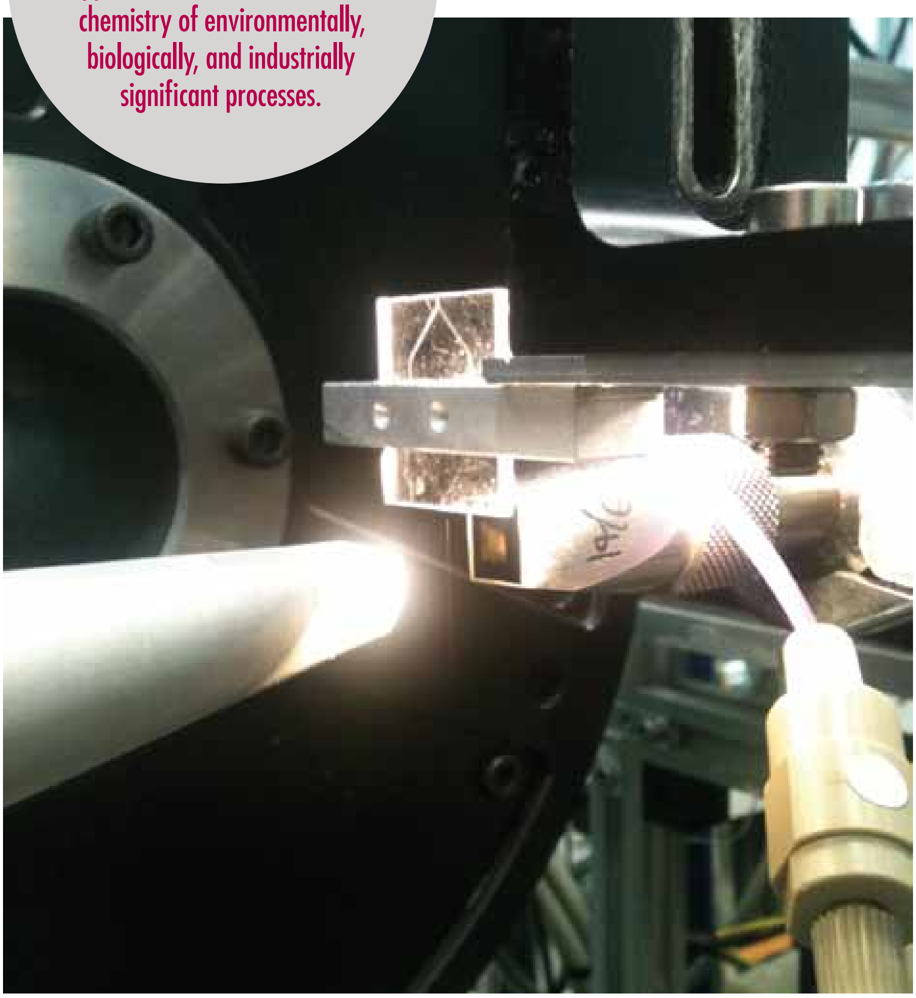
This process – which is known as interdigitising and can be likened to fingers being wrapped around each other – is repeated many times so that the final stream is a near perfect mixture of the original streams of liquid. All of this happens within a few millionths of a second, and observations can be made using various methods, such as X-ray scattering.

Collaborating with the Australian Synchrotron, the ANFF-SA research team has achieved the first real-time observations of phenomena that had previously only been predicted using computer simulations. Being able to measure the properties of these tiny minerals for the very first time provides important new insights into how the mineral formation process works, and how to potentially control it.

Understanding how molecules arrange themselves into minerals would provide exciting opportunities to understand the chemistry of environmentally, biologically, and industrially significant processes.

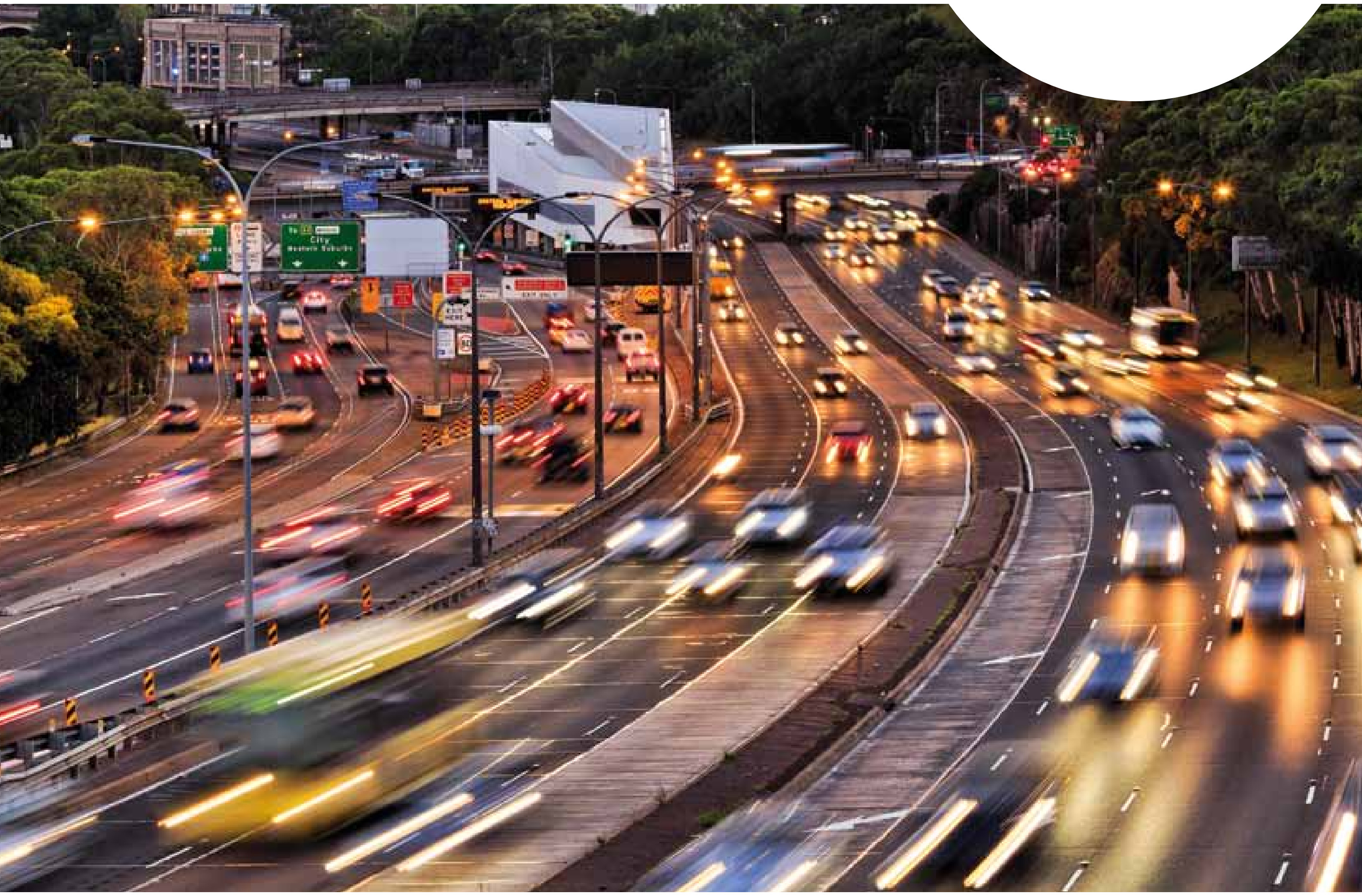
Aside from its scientific value, this research also heralds exciting new real-world possibilities for chemical production. Controlling reaction conditions at the nanoscale could, for example, eliminate the formation of unwanted by-products producing higher quality chemicals at a much lower cost than existing technologies. This technology will have applications in environmental science, medicine, engineering and other areas.

The team will now focus their efforts on new options for measuring and observing the mineral formation process on the device itself, to decrease the time between initiation and observation.



• *An early version of the free jet micromixer in operation at the Australian Synchrotron for X-ray scattering studies of calcium carbonate mineral formation.* Credit: Andrew Rose.

TRANSPORT



In a vast country like Australia, enabling people to move around in a way that is both sustainable and cost-effective is of critical importance. The identification of new potential fuel sources and technologies to handle them is a particular focus in the laboratories of ANFF facilities.

Understanding the hydrogen release mechanism

Clean, renewable and plentiful, hydrogen can be harnessed to fuel the modern world. The storage of hydrogen in solid form, such as MgH_2 (magnesium hydride) is a technique that is being developed for deployment in hydrogen stations for industrial and vehicular applications with minimal associated pollution.

The question scientists have come up against in the past is how to store suitable quantities of hydrogen safely while still allowing for its release in a timely and economically viable manner. One solution has focused on storing hydrogen in a solid state like MgH_2, which is a combination of magnesium and hydrogen.

The mechanisms by which hydrogen is added (hydriding) and removed (dehydriding) from the magnesium has long been the subject of debate. The common belief in the past has been that dehydriding hydrogen from magnesium occurred in line with a 'shrinking core' model, in which hydrogen atoms are released from the surface of the hydride particles. This belief has been based on results gleaned from studying extremely thin samples or nanoparticles.

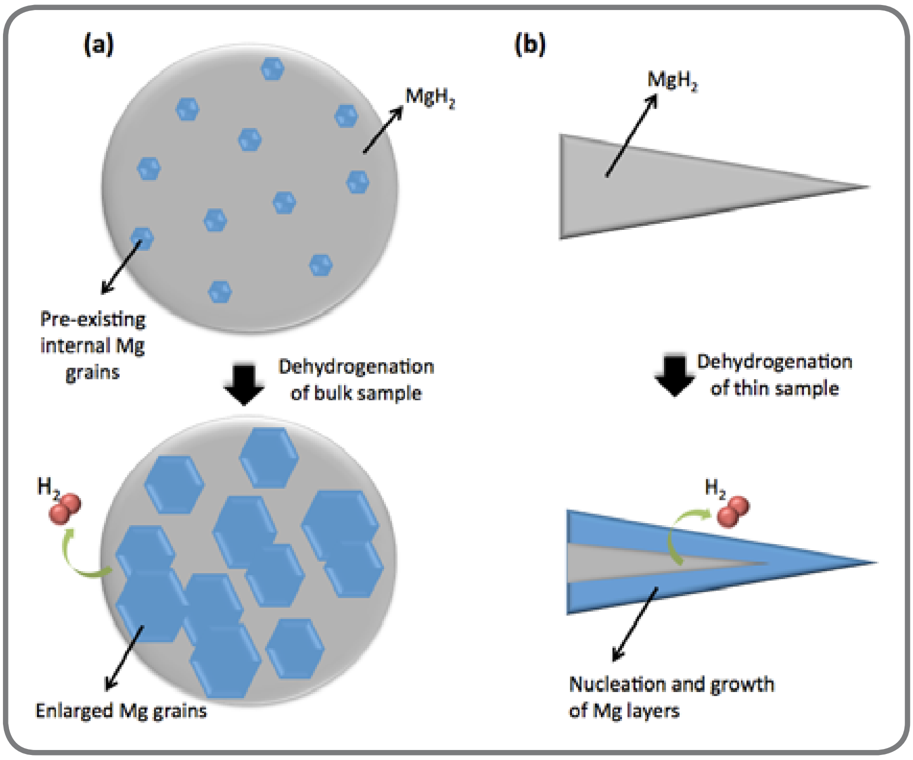
Researchers at the University of Queensland in the ANFF-Q node have recently provided new evidence that this common belief is not true for bulk materials, which are used in industrial scale hydrogen storage systems. Their project, led by Dr Kazuhiro Nogita, has shown that in bulk MgH_2, dehydriding takes place by a process of nucleation and growth of magnesium grains, inside the bulk hydride particles but not from the surface of the particles. This finding will influence significantly the system operation conditions of hydrogen storage systems.

Using advanced technology including the Differential Scanning Calorimeter at ANFF-Q, the Ultra-High Voltage Transmission Electron Microscope at Kyushu University in Japan and the Synchrotron Powder X-Ray Diffraction at the Australian Synchrotron, the research team were able to observe the behavior of hydrogen release from bulk materials in real time.

This work will contribute significantly towards the development of large scale commercial hydrogen storage systems, and therefore towards efficient and safe hydrogen filling stations for fuel cell vehicles in modern transport systems.

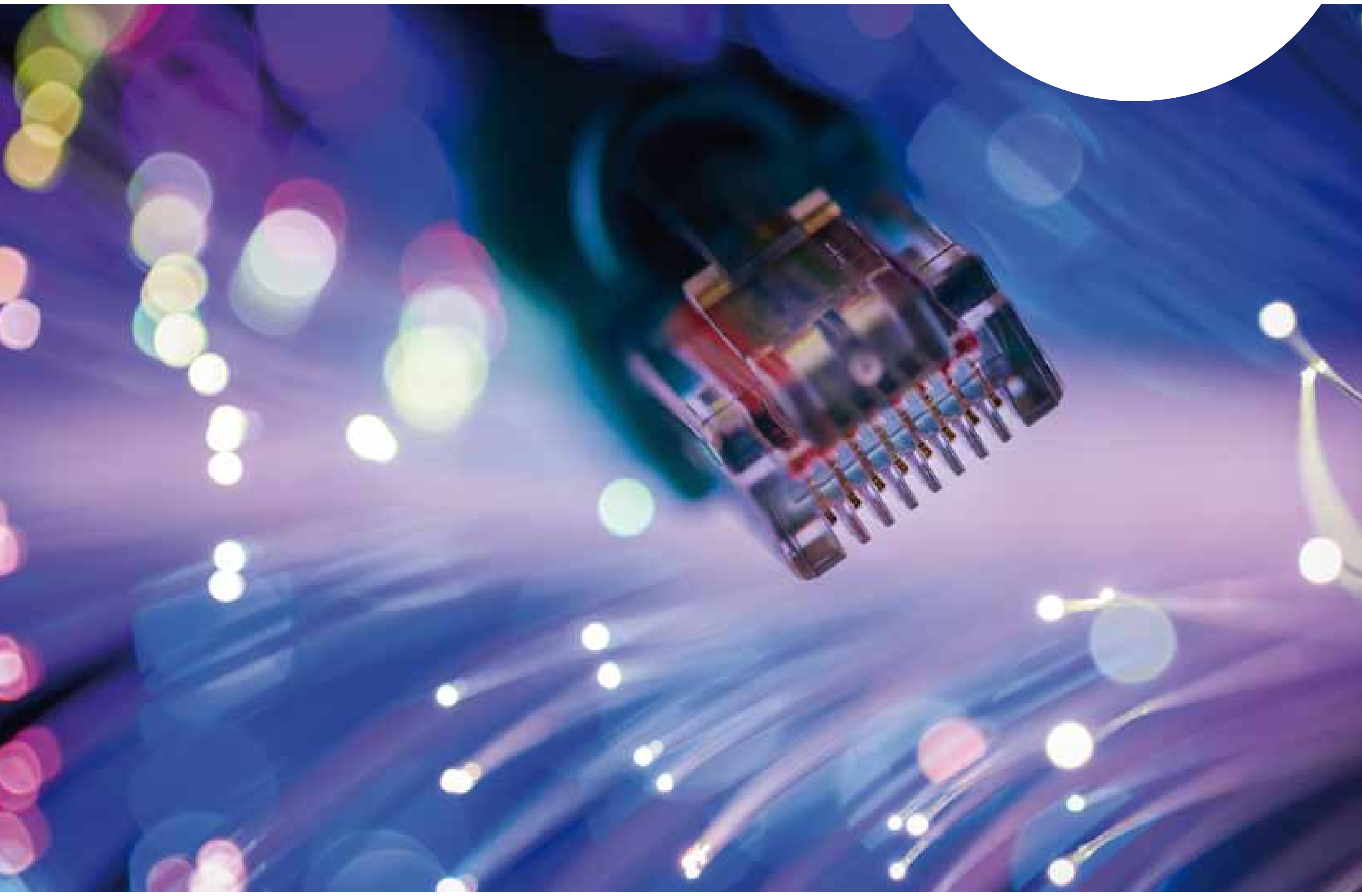
This unprecedented discovery led to the publication of *"Evidence of the hydrogen release mechanism in bulk MgH_2"* in *Scientific Reports**, a high-impact journal published by the *Nature* publication group. This work will contribute significantly towards the development of large scale commercial hydrogen storage systems, and therefore towards efficient and safe hydrogen filling stations for fuel cell vehicles in modern transport systems.

**Nogita, K. et al. Evidence of the hydrogen release mechanism in bulk MgH_2. Sci Rep 5, 8450, doi:10.1038/srep08450 (2015).*



• *Schematic hydrogen release mechanisms from a MgH_2 grain: (a) multiple 'nucleation and growth' model for bulk MgH_2 grains and (b) 'shrinking core' model for thin MgH_2 TEM samples.* Credit: (SCIENTIFIC REPORTS | 5 : 8450 | DOI: 10.1038/srep08450).

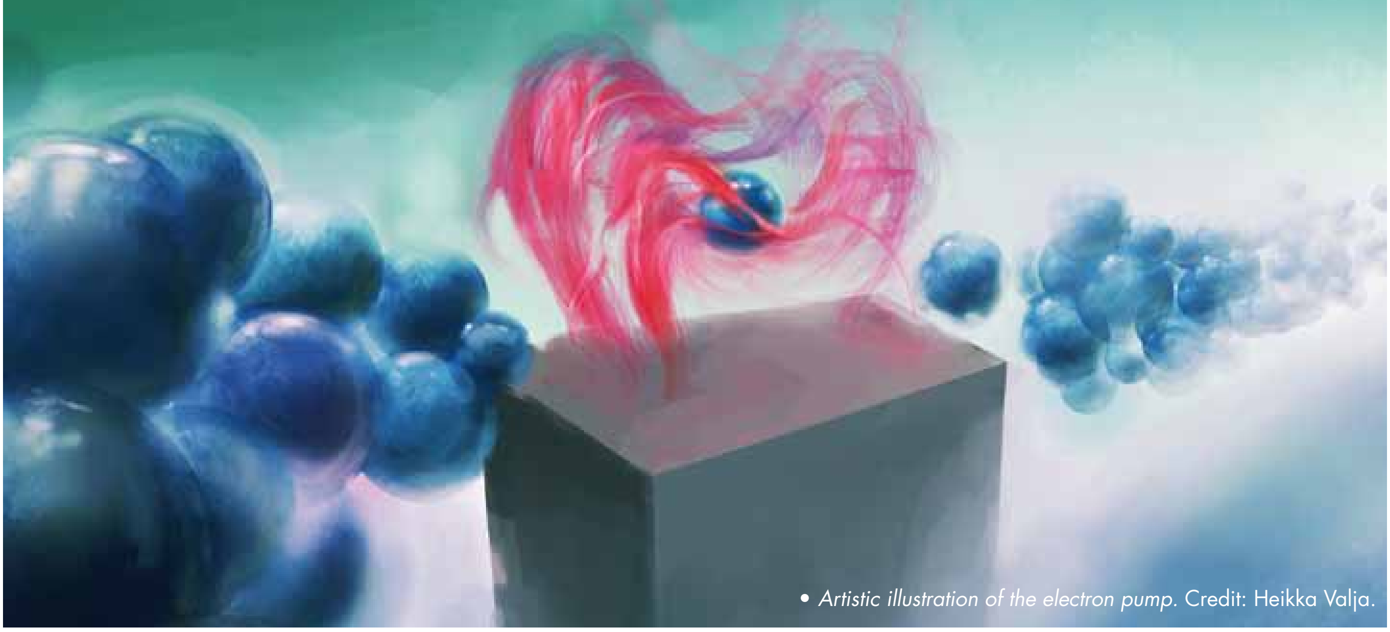
CYBERSECURITY



In the modern world, the cyber landscape is just as real as the physical one. Cyber infrastructure is relied upon by government, business, defence, emergency services, and the wider community, making its security of paramount importance.

Quantum science is an area where Australia excels on an international stage, with two ARC Centres of Excellence active in the area.

Quantum technologies evolving from this science will deliver many capabilities to the cyber world that are beyond the capacity of classical computers. These will be of immense importance for Australia's cybersecurity future.


• *Artistic illustration of the electron pump.* Credit: Heikka Valja.

Transistor pumps electrons one by one

Scientists have now pumped electrons with a silicon transistor more accurately than ever before. This device fabricated at the ANFF-NSW node can potentially be used to set a new definition for the ampere, the unit of electric current.

Accurate and fast electron pumping has been an important scientific and technological goal for decades. Now scientists have pumped 500 million electrons per second with 99.997% accuracy. The electron pump was a quantum-dot transistor fabricated using scalable silicon technology.

"We have now a very strong position in the worldwide race for a practical quantum current source," said a happy Dr Mikko Möttönen from Aalto University, Finland.

Electron pumps promise higher accuracy and stability for electric current than any other device. They can trigger a revolution in the international system of units whose definition of the electric current, the ampere, is still unsatisfactory.

"A change in the international system of units would be an historic event," said Prof. Andrew Dzurak, Director of the NSW Node of ANFF, Australia. "We are very close."

Although the silicon electron pump is fast enough, its accuracy still needs to be improved before it can serve in the redefinition of the ampere. To this end, there are no obstacles in sight. In fact, the accuracy of the pump may already be better than promised since statistical uncertainty prevented the researchers from observing higher accuracies than 99.997%.

"We are all set for an amazing breakthrough. Of course, we need hard work from scientists like Dr Alessandro Rossi and Tuomo Tanttu who were very important in this research," said Dr Möttönen.

"We have realised a nano-device that has the capability of generating a highly stable macroscopic current by governing the motion of individual electrons," said Dr Rossi.

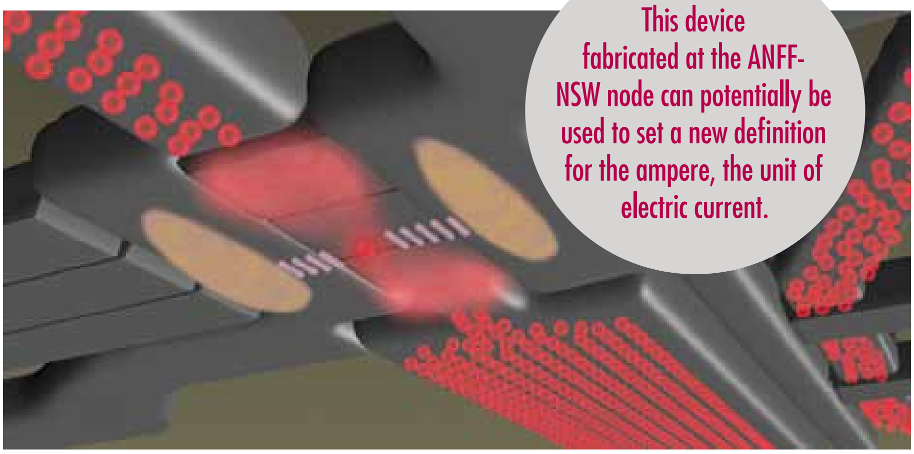
Recently the Academy of Finland awarded a research grant of 260,000€ to Dr Kuan Yen Tan to work in this electron pumping collaboration at QCD Labs, Aalto University. The Australian part of the research is supported by the Australian Research Council (ARC) through a discovery project led by Prof. Dzurak and Dr Möttönen. They, along with Dr Rossi, have also applied for new ARC funds to improve the accuracy of the pump such that it can serve as the realisation of the quantum current standard.

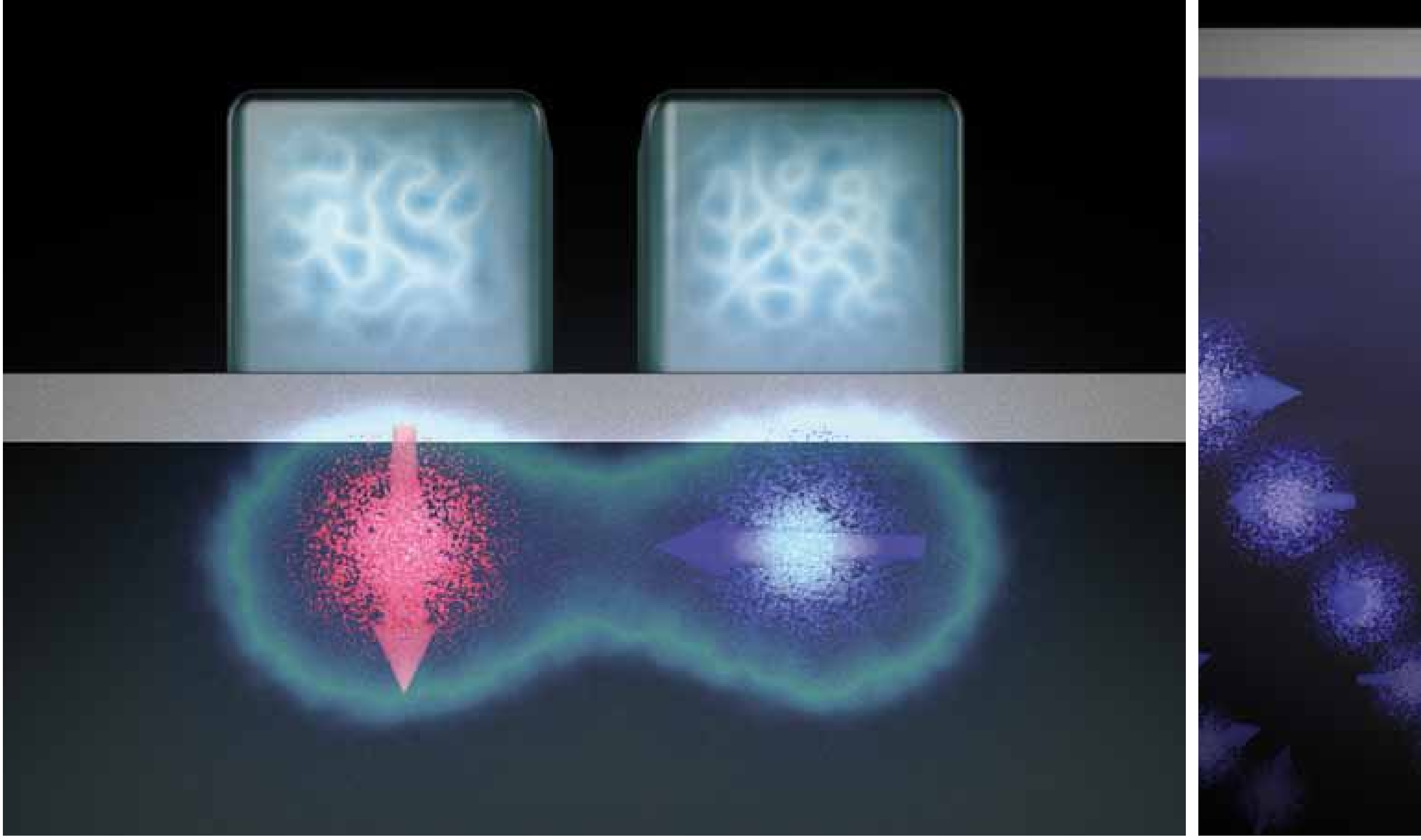
"Our collaboration with the Centre for Metrology and Accreditation, MIKES, has been very important in confirming the accuracy of our pump," said Möttönen.

The work on the electron pump was published in the high impact academic journal *Nano Letters**.

**Rossi, A. et al. An Accurate Single-Electron Pump Based on a Highly Tunable Silicon Quantum Dot. Nano Letters 14, 3405-3411, doi:10.1021/nl500927q (2014).*

This device fabricated at the ANFF-NSW node can potentially be used to set a new definition for the ampere, the unit of electric current.


• *"Schematic illustration of the device used in the experiments. The transistor's metal gates are shown in grey. Red spheres represent electrons. Accurate single-electron pumping is achieved via the interplay of electrostatic confinement and tunnelling phenomena, graphically highlighted in yellow and pink, respectively."* Credit: Heikka Valja.



• *Artist's impression of the two-qubit logic gate device developed at UNSW. Each electron qubit (red and blue in the image) has a 'spin', or magnetic field, indicated by the arrows. Metal electrodes on the surface are used to manipulate the qubits, which interact to create an 'entangled' quantum state.* Credit: Tony Melov/UNSW.

Silicon Quantum Computing

In October 2015, a UNSW based research team cleared a final scientific hurdle, putting Australia years ahead of the rest of the world in an international race to build a silicon quantum computer.

ANFF-NSW has a long history in supporting local researchers in this race, which will see the development of a computer capable of calculations that are beyond the reach of classical computers and can be manufactured using current silicon fabrication technology.

This breakthrough, published in high profile science journal *Nature**, included details of a quantum logic gate they built in silicon for the first time, making calculations between two quantum bits of information possible.

"What we have is a game changer," said team leader Andrew Dzurak, Scientia Professor and Director of the NSW Node of the Australian National Fabrication Facility at UNSW.

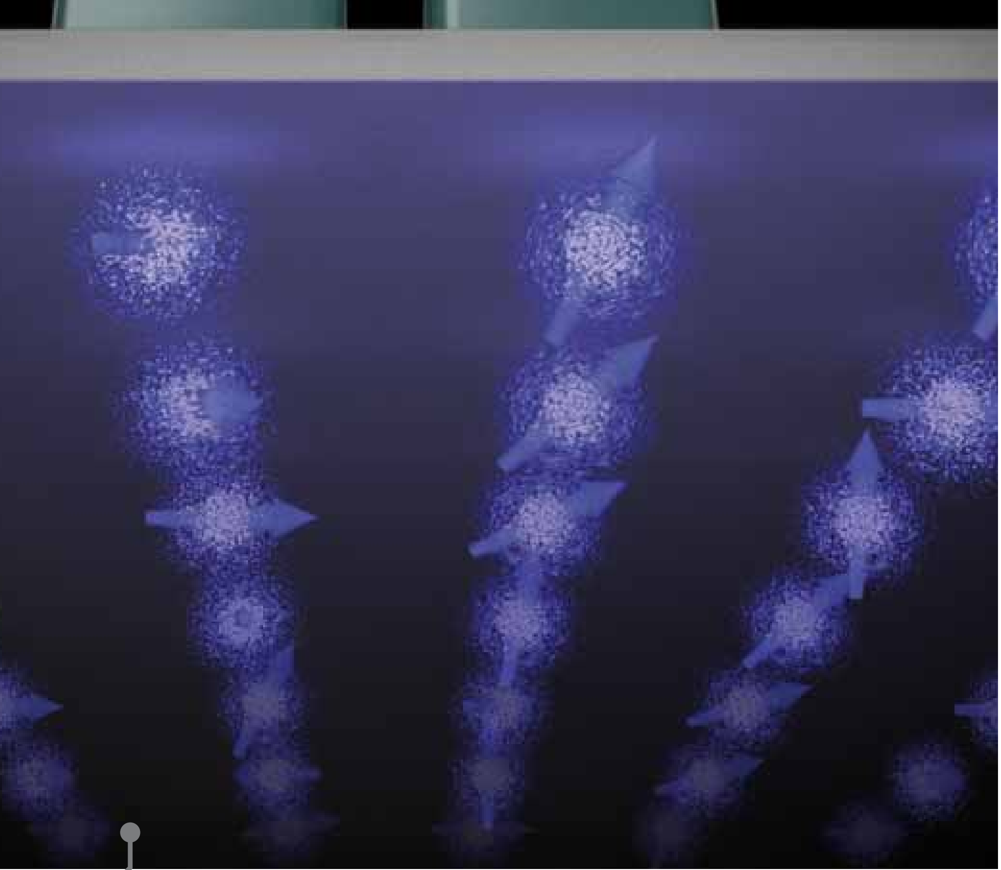
"We've demonstrated a two-qubit logic gate – the central building block of a quantum computer – and, significantly, done it in silicon. Because we use essentially the same device technology as existing computer chips, we believe it will be much easier to manufacture a full-scale processor chip than for any of the current leading designs, which rely on more exotic technologies.

"This makes the building of a quantum computer much more feasible, since it is based on the same manufacturing technology as today's computer industry," he added.

During 2015, the team also patented a design for a full-scale quantum computer chip that would allow for millions of quantum bits (qubits), all doing the types of calculations that were demonstrated in their *Nature* paper. This patent won the team a UNSW Innovation prize, and marked the eve of their entrepreneurial endeavours to bring silicon quantum computers into the world.

"The next step for the project is to identify the right industry partners to work with to manufacture the full-scale quantum processor chip," said Dzurak.

Quantum computers operate differently from regular computers. Unlike a regular bit, which is either in a "0" or "1" state, a qubit can exist in both of these states at once, a condition known as a superposition. A qubit operation exploits this quantum weirdness by allowing many computations to be performed in parallel (a two-qubit system performs the operation on 4 values, a three-qubit system on 8, and so on). This is their key advantage



• *Artist's impression of a full-scale silicon quantum computer processor, with thousands of individual qubits, each one being a single electron, with its associated spin. The new UNSW design means that existing industrial silicon CMOS plants can be used to make quantum processor chips.* Credit: Tony Melov/UNSW.

that leads to their ability to perform computations that classical computers cannot, such as the factorisation of large numbers.

Such a full-scale quantum processor would have major applications in the cyber security, finance and healthcare sectors, allowing the identification and development of new medicines by greatly accelerating the computer-aided design of pharmaceutical compounds (and minimising lengthy trial and error testing); the development of new, lighter and stronger materials spanning consumer electronics to aircraft; and faster searching through large information databases.

This and many other related quantum technologies are being developed by two ARC Centres of Excellence supported by ANFF: the Centre of Excellence for Quantum Computation and Communication Technology (CQC2T), where this work was developed; and the ARC centre of excellence for Engineered Quantum Systems (EQUS).

**Veldhorst, M. et al. A two-qubit logic gate in silicon. Nature 526, 410-414, doi:10.1038/ nature15263 (2015).*

• *Press Conference announcing the first Quantum Logic Calculations in Silicon, with ANFF CEO Rosie Hicks, ANFF-NSW Node Director Prof Andrew Dzurak, and CQC2T researcher Dr Menno Veldhorst.* Credit: Grant Turner, UNSW.

David Lancaster – co-founder of Red Chip Photonics

Red Chip Photonics Pty Ltd is an Australian-based start-up company co-founded by Professor David Lancaster, Director of the Laser Physics and Photonics Devices Lab at the University of South Australia, and Professor Tanya Monro, Deputy Vice Chancellor at the University of South Australia.

The company is commercialising a new chip laser architecture, which was created by harnessing the expertise of ANFF's OptoFab node and linking ZBLAN glass fabrication capabilities at the University of Adelaide with the ultra-fast laser inscription facilities at Macquarie.

This chip laser technology has already won an ARC Linkage Grant, and there is significant interest in the new lasers from Defence, Mining, Spectroscopy and Medical companies. David is now building a team to create a major Australian-based laser company, with an intention to establish laser manufacturing in South Australia targeted at international markets.

For more information, visit www.redchipphotonics.com.

ENERGY

Australia's energy future calls for lower carbon emissions and low-cost renewable sources. Effective storage of renewable energy is also very important. R&D at ANFF nodes around Australia is supporting these objectives.

Taking the heat out of solar

The global drive towards making solar energy more competitive against low cost fossil fuels has given rise to some amazing solar technologies. However, solar energy has been held back by an issue many might find surprising: for every 10°C increase in operating temperature, most solar cells become around 5% less efficient in converting sunlight into electricity.

Under the powerful Australian sun, this means that a typical house photovoltaic (PV) system with an optimum output of 3kW per hour would have that yield reduced by 150W for every 10°C increase in temperature. In fact, the system could provide more power on a sunny winter's day than a sunny summer's day.

This largely negates the efficiency improvements researchers have achieved for crystalline cells over the last few decades.

Since 2013, the CSIRO Microfluidics team led by Dr Yonggang Zhu has been developing a new thermal management system to address some of the fundamental challenges associated with solar photovoltaic technologies. The project is part of a $4 million SIEF (Science and Industry Endowment Fund) project – 'High performance solar cell technology with integrated nanoplasmonic thin film and thermal management systems.' In this project, Swinburne University of Technology and CSIRO researchers are working jointly to overcome the efficiency losses that solar cells suffer when exposed to high temperatures.

In tackling this problem, the CSIRO team has developed a novel heatpipe plate system that can be integrated with PV panels. The system utilises unique microscale thermal and fluid behaviors to remove heat with high efficiency. The devices were fabricated and tested in the Micro and Nanomanufacturing Laboratory, an ANFF Victoria facility based at the CSIRO Clayton site.

The heatpipe plate is fabricated from metal materials and has a thickness of a few millimeters. It can be mass-produced at low cost. While there is internal microflow within the plate, the integrated device has no moving parts and should last for 10–20 years, making it ideal for integration with PV panels.

The technology developed from the project will generate benefits in the energy sector by recovering up to 15% of the electricity that is lost due to heating. The technology can also be applied in a variety of other industries, including electronics, energy storage, chemical reactors and spacecraft. Future work will focus on the integration of the system with PV panels and mass production techniques.

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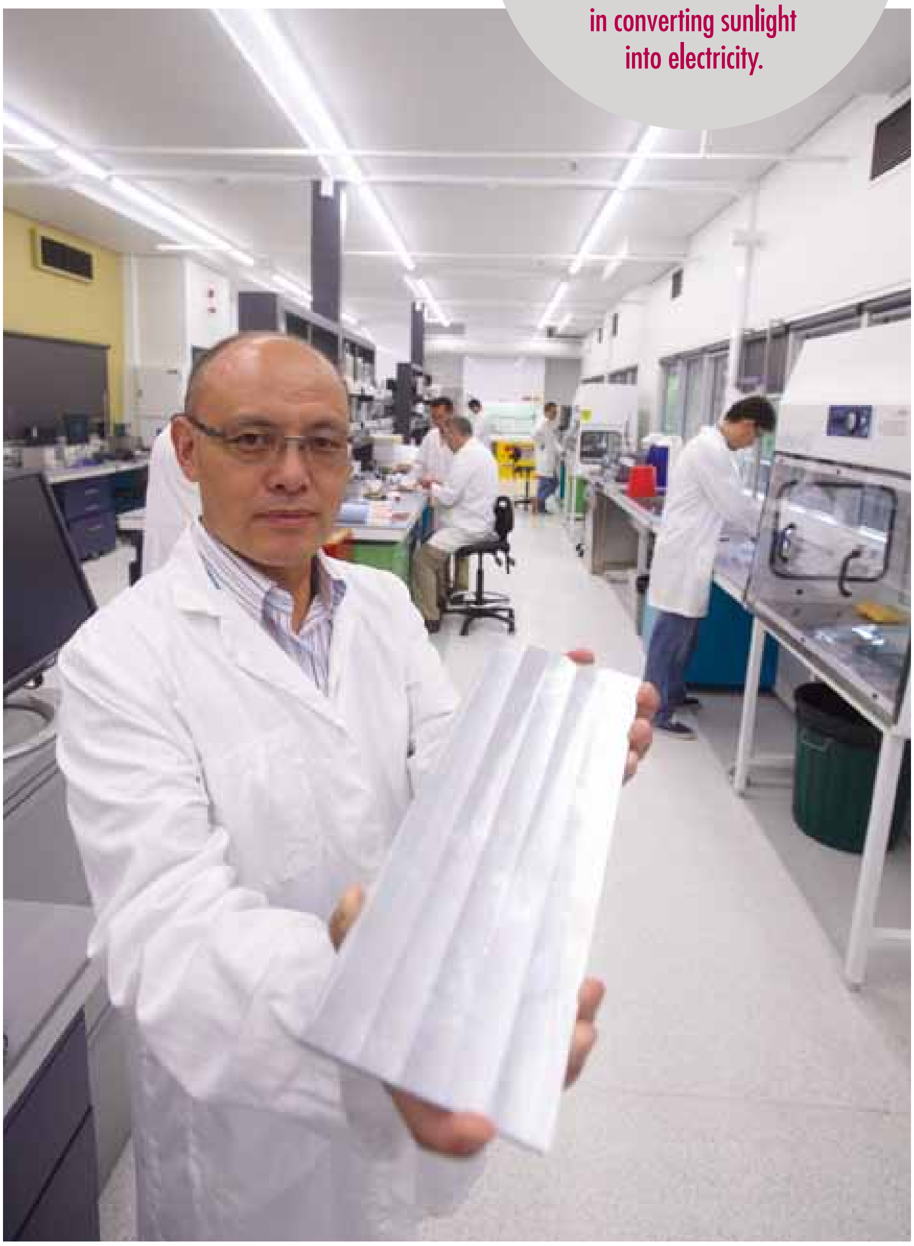


• *A prototype heatpipe plate device developed at CSIRO held by Dr Yonggang Zhu.*

Mimicking leaves to transform sunlight into chemical energy

The chemical industry relies heavily on fossil fuel-derived energy to produce the materials upon which we base modern society.

A more sustainable and desirable prospect is to use sunlight to energise chemical reactions, transforming the industry into a solar chemical manufacturing industry.

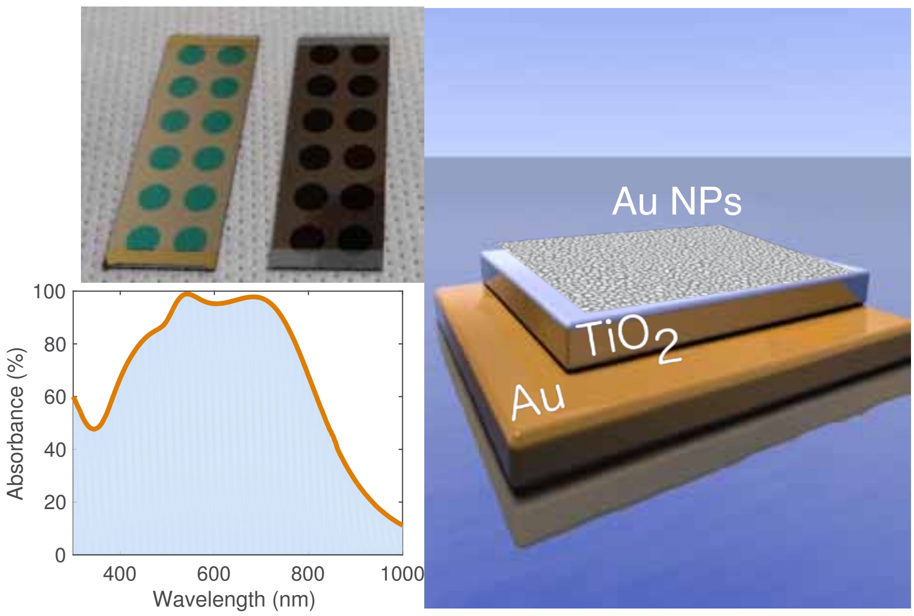
A team of research scientists in CSIRO is developing materials that can harvest solar energy and transform it into chemical potential energy by mimicking the natural processes of leaves.

A team of research scientists at CSIRO is developing materials that can harvest solar energy and transform it into chemical potential energy by mimicking the natural processes of leaves. The research has led to publications in the high impact journals *Nanoscale* and *Advanced Optical Materials*.

Initially, the team used the high-resolution Electron Beam Lithography tool at the Melbourne Centre for Nanofabrication in the ANFF-Vic node to create structures capable of efficiently harvesting light for driving chemical transformations and demonstrated a two-orders of magnitude improvement in the rate of a model chemical reaction.

More recently, the team has created 'super-absorber metasurfaces' which can absorb nearly 100% of the incident light. These structures are made from a single layer of metal nanoparticles deposited on top of thin films of a semiconductor material that in turn is supported by a mirror. In these super-absorber metasurfaces, the metal nanoparticles absorb light which results in the excitation of collective oscillations of surface charges commonly referred to as surface plasmons. When the metal nanoparticles are deposited on semiconducting surfaces, non-radiative relaxation of surface plasmons can result in the transfer of energetic electrons into the semiconductor, resulting in a charge separated state (electron in semiconductor and hole in metal) with sufficient chemical potential energy to drive chemical transformations, such as the generation of hydrogen (a chemical feedstock) from water.

The ability to tune the optical properties of metal nanoparticles offers the potential to create new and more efficient ways of directing light energy into targeted chemical reaction pathways. The team envisage that these light-harvesting technologies are a potential avenue for developing a future chemical industry where chemicals are synthesised using sunlight: a renewable source of chemical potential energy.



• *Super-absorber concept. Top left: Fabricated structures using simple and inexpensive physical vapour deposition techniques. The dots are the super-absorber areas. Bottom left: Measured absorbance spectrum demonstrating high broadband light absorption by a device that is only c.a. 40 nm in thickness. Right: Diagram of one embodiment of the concept using metal nanoparticles as the active layer, TiO_2 as the dielectric coating.* Credit: Daniel Gomez.

Novel materials for better batteries

Lithium-ion batteries are currently used in everyday devices such as portable electronic devices and power tools. They are also of interest for other emerging applications including electric vehicle batteries and for storage of energy harvested by solar cells.

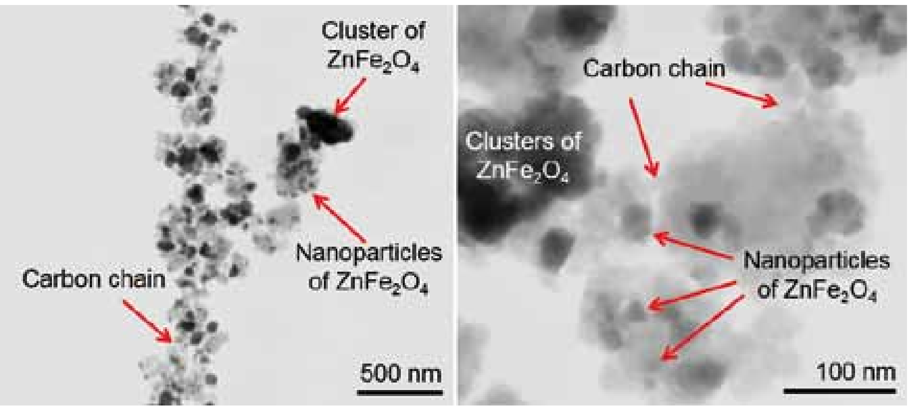
To improve both the charge capacity and lifespan of these batteries, alternative materials for battery electrodes are currently being investigated by Dr Alexey Glushenkov from Deakin University at the Melbourne Centre for Nanofabrication (MCN), in the ANFF-Vic node. These new materials are expected to store more charge and remain active for longer periods of time. To select and optimise these materials, characterisation by electron microscopy is required to understand their structure and performance.

Using the FIB-SEM at MCN, which is fitted with Scanning Transmission Electron Microscopy (STEM) detectors, Dr Glushenkov is able to select and study new electrode materials for Li-ion batteries. The electrode materials are synthesised by his team at Deakin University in a joint effort with Dr Md Mokhlesur Rahman. The unique capability of the FIB-SEM instrument available at MCN is its ability to perform Scanning Electron Microscopy (SEM) and STEM on the same specimen simultaneously. This allows researchers to understand the morphology of materials, their structure and their composition at the same time, without the need to use multiple instruments. In addition, the Focused Ion Beam available on the instrument can precisely slice specimens when required.

The composite of zinc iron oxide with carbon developed by researchers at Deakin can store a large amount of charge and retain its charge storage ability for an extended life-span.

The team has recently produced a novel nanocomposite material in which zinc iron oxide ($ZnFe_2O_4$) is mixed with carbon. Zinc iron oxide is seen as an interesting electrode material for batteries but it usually cannot deliver sufficient charge storage and its ability to operate in a battery deteriorates quickly. However, the composite of zinc iron oxide with carbon developed by researchers at Deakin can store a large amount of charge and retain its charge storage ability for an extended life-span. The team have established that the attractive charge storage ability was achieved due to a unique nanostructure of the composite which consists of chains of carbon material decorated with oxide nanoparticles. These results were published in the *Journal of Power Sources**.

This project holds great potential for the development of better electrode materials for batteries and, as a result, more reliable, longer lasting and cheaper batteries with higher charge storage capacities. In turn, this benefits portable electronic devices, power tools, electric vehicles, integrated solar cell-battery packs and many other applications.



• *Low magnification (left) and high magnification (right) STEM images of $ZnFe_2O_4$-carbon nanocomposite electrode for Li-ion batteries.* Credit: Dr Alexey Glushenkov. Reproduced from R.M.Thankachen et. al., Journal of Power Sources 282 (2015) 462-470.

**Thankachan, R. M. et al. Enhanced lithium storage in ZnFe2O4–C nanocomposite produced by a low-energy ball milling. Journal of Power Sources 282, 462-470, doi:10.1016/j.jpowsour.2015.02.039 (2015).*

RESOURCES

The resources sector is a significant contributor to Australia's economy, and continued research is needed to ensure its long-term value. Scientists at ANFF nodes around the country are working to make the resource extraction and distribution process as sustainable, safe and efficient as possible.

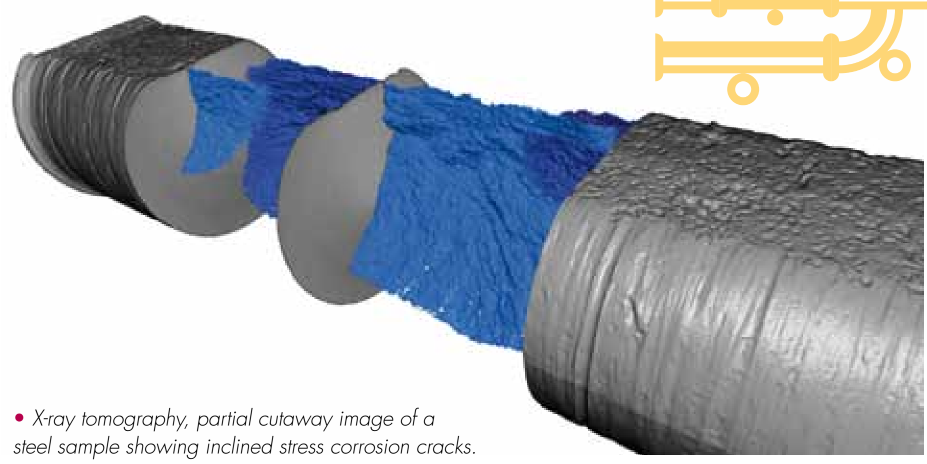
Steps towards safer pipelines

Steel pipelines are heavily relied upon in the oil and gas industry to transport resources to where they are needed. Undetected flaws in steel pipelines can result in catastrophic gas explosions, such as the gas explosion in San Bruno, California in 2010.

Detecting flaws in steel pipelines is challenging due to the fact that the cracks have complex shapes and interactions with each other. Technology recently developed at the University of Adelaide provides a more detailed understanding of how stress corrosion cracks develop and grow in steel pipelines and takes a significant step towards safer, more efficient pipelines.

X-ray tomography has been used in the past to analyse microscopic samples of aluminium, however, due to the density of steel, it was not known whether these techniques could be carried across effectively.

The project carried out by the research team utilised the X-ray tomography capabilities at the ANFF-SA node to carry out a methodical study of the imaging potential of different thicknesses of steel, with the aim of maximising the size of the sample and achieving a resolution ideal for studying the cracks. Following this process, the team was able to achieve ideal resolution on steel samples of up to four millimetres.



• X-ray tomography, partial cutaway image of a steel sample showing inclined stress corrosion cracks.

Technology recently developed at the University of Adelaide provides a more detailed understanding of how stress corrosion cracks develop and grow in steel pipelines.

Having gained a better understanding of the parameters within which flaws in steel can be detected, the researchers are now focusing on further expanding this knowledge to increase the size of samples that can be analysed and improve the image resolution.

This work provides theoretical proof that flaws within steel can be detected using X-ray tomography techniques, however there are significant engineering challenges to be tackled before this technique can be taken out of the laboratory and into the field.

With further development, this technology could provide a viable technique for detecting flaws in steel pipelines during the manufacturing process, and help to ensure safer and more efficient oil and gas pipelines.

Streamlining the Bayer process

The Bayer process is the principal method for refining bauxite into aluminium oxide (alumina), which is used to make aluminium metal. During the production of alumina via the Bayer process, aluminium hydroxide (gibbsite) is crystallised from solution. A common problem encountered during this process is the generation of finely sized gibbsite particles through secondary nucleation (when new particles form on the surface of existing particles). These fine particles are undesirable because they are difficult to separate and classify, and can cause dusting issues at aluminium smelters.

Drs Weng Fu and James Vaughan from the University of Queensland, together with Dr Alistair Gillespie from Rio Tinto, have recently identified a new approach for removing the gibbsite fines from the aluminium production process.

The researchers used a synthetic solution, sodium oxalate, to mimic the effects of the highly alkaline Bayer liquor used during the industrial production of alumina. Using Atomic Force Microscopy (AFM) at ANFF-Q, the team observed the gibbsite interacting with sodium oxalate during the crystallisation process and discovered that the fine gibbsite nuclei could be completely encapsulated in the faster growing sodium oxalate crystal.

This discovery provides new insight into modelling and controlling the Bayer process, an old technology with high economic value to the Australian resources industry. The research team is currently considering ways that this approach to eliminating gibbsite fines could be practically implemented in the alumina production industry.

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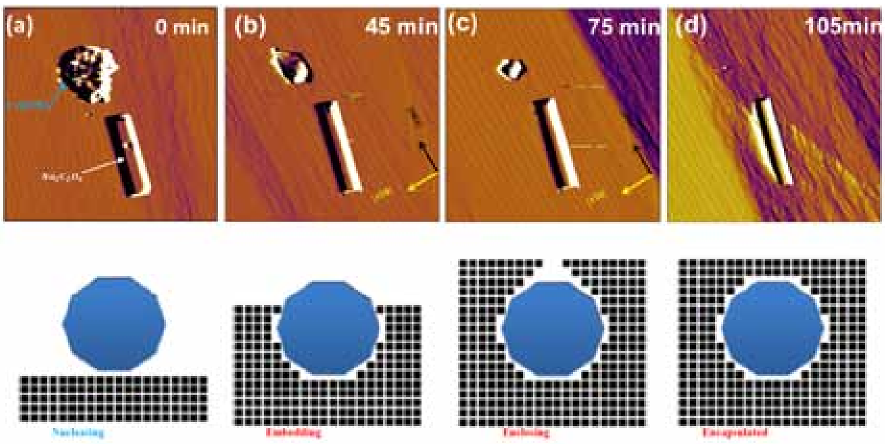

• *Fine gibbsite immobilisation in a fast growing sodium oxalate crystal.* Credit: Weng Fu and ANFF-Q. This image was previously published in *Crystal Growth & Design*.

Better sensors for mining environments

Sensing technology is needed to accurately monitor tool performance and working environments in the resource extraction industry. However, state-of-the-art conventional sensors are not robust or reliable enough to endure the harsh environments of mine sites.

Using unique fabrication technology, researchers at Griffith University have developed world-first silicon carbide nanowires for use in nanoscale sensors that are suitable for harsh environments. The technology is based on the superior properties of silicon carbide nanowires, which are thousands of times smaller than a strand of human hair and extremely sensitive and robust compared to existing sensor technology.

Using facilities at the Queensland Micro and Nanotechnology Centre (QMNC) in the ANFF-Q node, the research team was recently the first in the world to successfully grow device-grade silicon carbide films onto large silicon wafers. They were then able to fabricate silicon carbide nanowires from the film using Focused Ion Beam, Electron Beam Lithography, and etching processes. The silicon carbide nanowires have shown excellent properties for the detection of stress and strain.

Future work will focus on using these nanowires to develop robust nanoscale sensing devices capable of detecting pressure, vibration, and temperature in mining sites and mining tools to enhance the safety and productivity of resource extraction. Ongoing work is being supported by a multinational company and there is a great potential for this technology to be commercialised by Australian mining companies.

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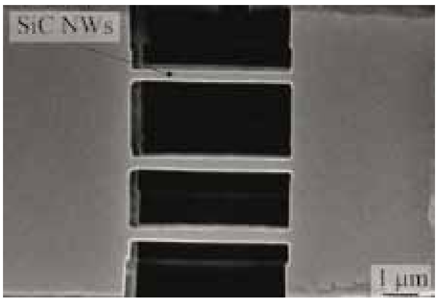


• *Scanning Electron Microscope (SEM) image of silicon carbide nanowire array for highly sensitive mechanical sensing application in harsh environments.* Credit: Dr Dzung Dao, Queensland Micro and Nanotechnology Centre, Griffith University, Queensland.

ADVANCED MANUFACTURING

Innovative products and techniques are needed to give Australia a competitive edge in the global market. Current scientific research is working towards developing and supporting existing industries while contributing to the industries of the future.

• *The roll-to-roll coating line at the Materials Node, Newcastle.* Credit: NIER, University of Newcastle.

Painting the future of solar

Consider a planet that is able to harness the abundant light energy that it receives every second of every day. Imagine a society where low cost energy is accessible by all. Picture a city where every building, every vehicle and every device has a coating that generates electricity when light shines on it. This is the vision for Organic Solar.

Organic solar cells are a third generation solar technology that use conducting plastic to convert sunlight into electricity. They are lightweight, flexible and can be produced with significantly less expense than conventional silicon solar cells. The lower cost of organic solar modules suggests this solar technology could compete on a direct cost basis with conventional power generation sources such as coal and gas.

The Solar Paint initiative from the Centre for Organic Electronics (COE) at the University of Newcastle aims to produce organic solar cells using environmentally sound water-based techniques. This exciting research has produced promising experimental results and now the process of taking Solar Paint from the laboratory to the rooftop has begun.

Using the ANFF Roll-to-Roll (R2R) coating facilities at the University of Newcastle the COE has begun pilot scale studies of organic solar modules. Comprised of multiple layers, the solar modules are fabricated using industry standard techniques such as flexographic coating, slot-die coating or sputter coating.

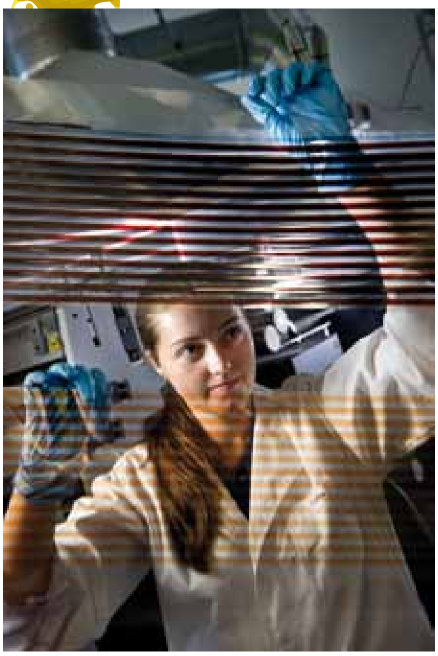
"Having access to a facility where these coating techniques are available is critical to this project," said Dr Thomas Rieks Andersen, one of the lead researchers on the Solar Paint project. "We are able to create hundreds of metres of samples in a few hours and test many of the key parameters. Scaling this technology from small laboratory-based cells up to multi-metre sized modules would not be possible without the ANFF coating facility."

The Solar Paint team is now testing various electrode and electrical generation layers within the larger modules being created on the R2R equipment.

"Projects such as Solar Paint are the reason this facility was created," said Dr Ben Vaughan, ANFF lab manager at the Materials Node. "There are only a handful of installations worldwide that have these coating and printing capabilities along with the expertise to help develop a technology like organic solar."

The Solar Paint initiative is moving us closer to a world of low cost energy for all.

This exciting research has produced promising experimental results and now the process of taking Solar Paint from the laboratory to the rooftop has begun.



• *Acadia Lyons examines an organic solar cell layer coated at the Materials Node, Newcastle.* Credit: NIER, University of Newcastle.

A world first for graphene-based energy storage

The ever-increasing demand for small, portable electronic devices such as electronic wristbands has created a gap in the energy storage market. These devices are small, and often do not have room for a standard battery or supercapacitor in their electric circuitry. Instead, researchers at Griffith University have developed a novel process for fabricating graphene-based micro-supercapacitors that can be directly integrated into the device's electric circuit.

Supercapacitors charge quickly, store a large amount of energy, and have a much longer operational life than conventional batteries, making them suitable for use in modern devices. Graphene is uniquely suited for developing next generation supercapacitors due to its tremendous elasticity, mechanical strength, high surface area, and minimal weight. However, graphene is also difficult to work with and easily damaged, and scientists have struggled to translate its potential from the laboratory into the real world.

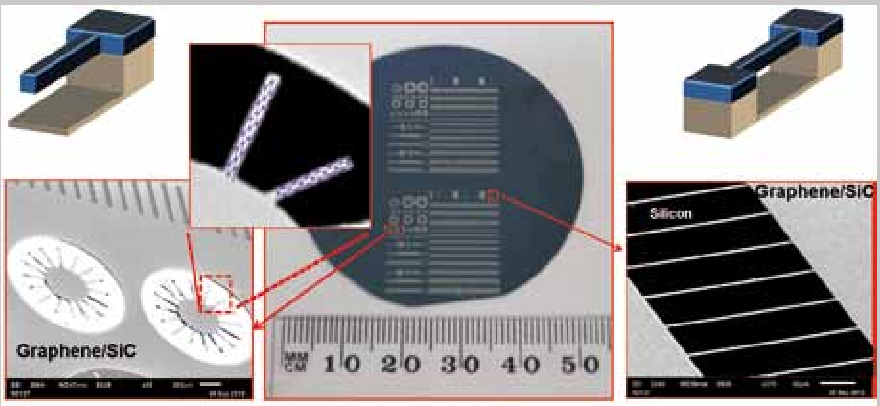
The research team, led by Associate Prof. Francesca Iacopi, have been working with the support of the ANFF-Q node to overcome these issues by growing the graphene directly onto the silicon wafer. First, a thin layer of silicon carbide is grown on the silicon wafer using a heat treatment with the desired surface pattern achieved through photolithography and etching techniques. Graphene can then be evolved on top of the silicon carbide using metal catalysts and a high temperature graphitisation method under vacuum conditions.

> **The team were able to achieve a world first: the fabrication of graphene-based micro-devices using silicon carbide films on silicon wafers.**

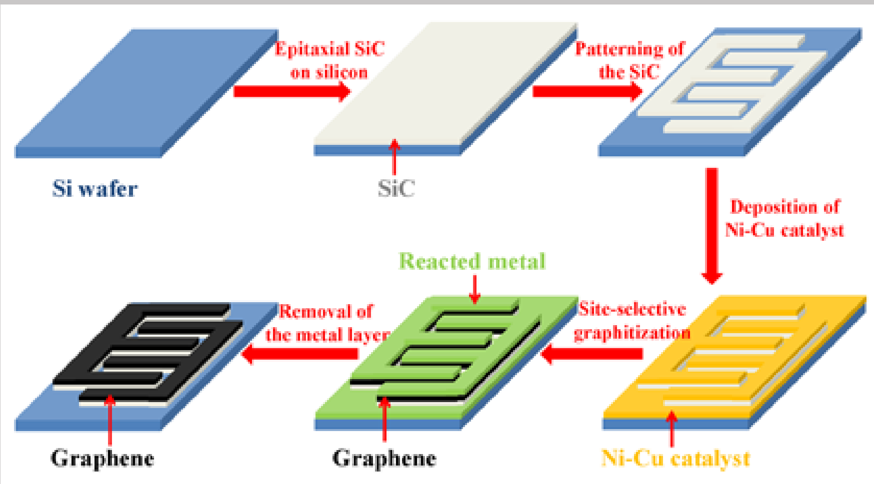
Following this process, the team were able to achieve a world first: the fabrication of graphene-based micro-devices using silicon carbide films on silicon wafers. Further work will focus on optimising the synthesis conditions and device dimensions to further improve performance.

The novel techniques used in the project can be directly applied in the micro-fabrication industry to fabricate practical electronic components for integrated, high performance energy storage in small portable devices.

The research team is now working with US Air Force Research Laboratory to continue developing the technology, and this work also offers Australia the chance to develop a local industry around the low-cost manufacture of high performing micro-sized energy units.



• *World's first water-scale patterned graphene on SiC/Si as a platform for micro-devices.* Credit: B.V.Cunning et al., *Nanotechnology* 25 (2014) 325301.



• *A schematic diagram showing the fabrication strategy for interdigitated supercapacitors.* Credit: B.Wang, unpublished.

• *Radulock™ tubing connection ports as used in a high pressure 3D micromixing device.* Credit: Luke Parkinson.

• *Dr Luke Parkinson*

From research to revenue: Radulock™ direct tubing connection geometry

Researchers who spend their days developing cutting-edge technologies and innovative processes are uniquely positioned to become entrepreneurs. Dr Luke Parkinson, a Research Fellow at Flinders University and inventor of Radulock™ tubing connection ports, knows this first hand.

While working as Microfluidics Engineer at ANFF-SA, Dr Parkinson found that the difficulty in negotiating the fluid interface was preventing the mass uptake of microfluidic technologies. Existing methods for making the so called 'chip to world connection' required manifolds, expensive fittings and adhesives, or were simply unfit for commercial production.

Dr Parkinson and ANFF-SA solved this problem by producing thermoplastic microfluidic devices with novel porting geometry, known as Radulock™. The unique geometry allows for tubing to be directly fitted into the port without the need for any fittings, tubing preparation or adhesives. The resulting connection is completely reversible and withstands extremely high pressure with zero dead volume. The flexible design means that ports can be placed very close together and at any location without any surface protrusion. Radulock™ geometry is designed to suit high-volume manufacturing techniques such as injection moulding.

Such has been the success of Radulock™ ports that a private company, Radulock Pty Ltd, has been spun-off to manage licensing of the technology to international partner companies in the microfluidics, laboratory and medical consumable sectors.

Such has been the success of Radulock™ ports that a private company, Radulock Pty Ltd has been spun-off to manage licensing of the technology to international partner companies in the microfluidics, laboratory and medical consumable sectors. Several microfluidic devices currently undergoing commercialisation after prototyping at ANFF-SA include Radulock™ ports. Their easy operation, suitability for mass production and high pressure tolerance solve key problems and are a giant leap towards the mass adoption of microfluidic technologies.

Radulock™ ports may be specified in ANFF-SA thermoplastic devices with free academic and product development licences available from Radulock Pty Ltd. For more information go to **www.radulock.com** or email info@radulock.com.

Imaging with ATOMS

With modern fabrication methods taking advantage of an ever broader library of new materials, the techniques used to image the results must also evolve. In particular, many of the more delicate structures (including biological samples and organic thin films for polymer electronics) tend to suffer degradation under the energetic probes of traditional microscopies. A new kind of microscope, developed at the Newcastle arm of the ANFF Materials node, is set to eliminate this frustrating outcome and allow researchers to access a wide range of challenging new samples.

The SHeM is totally surface-sensitive and completely non-destructive, making it ideal in instances where exposure to high energy beams would limit experimental time or the reliability of the results.

The Scanning Helium Microscope, or SHeM, utilises helium atoms as the probe particle to provide an alternative solution for such materials. The helium atoms incident on the sample surface are inert, neutral, and have an energy several orders of magnitude lower than that of photons or electrons at comparable wavelengths. As a result, the technique is totally surface-sensitive and completely non-destructive, making it ideal in instances where exposure to high energy beams would limit experimental time or the reliability of the results. Furthermore, the nature of the probe-sample interaction does away with the requirement for any form of sample preparation (such as the coatings necessary to prevent charging and insulating samples with SEM).

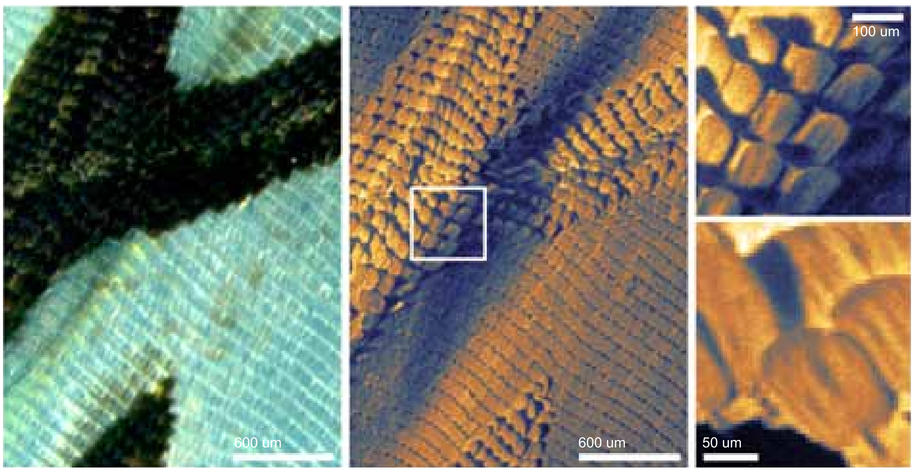
"The truly unique nature of the Scanning Helium Microscope provides us with a range of new and exciting opportunities with regards to understanding previously inaccessible systems. Of particular interest to the Centre for Organic Electronics here at Newcastle is the ability to image the delicate conducting polymers used to build plastic solar cells," said Prof. Paul Dastoor of the ANFF Materials Node.

• *The Scanning Helium Microscope at the ANFF Materials node, Newcastle.*

"In the future we also expect to be able to perform a type of 'chemical fingerprinting' with the helium beam, further expanding the applications of SHeM towards the development of new materials."

Using the instrument developed at the University of Newcastle (in collaboration with the Cavendish Laboratory at the University of Cambridge), investigations continue into harnessing the helium atoms to probe not only the shape of the surface, but to also examine dynamic surface processes.

Barr, M. et al. A design for a pinhole scanning helium microscope. Nucl. Instrum. Methods Phys. Res., Sect. B 340, 76-80, doi:10.1016/j.nimb.2014.06.028 (2014).



• *Top: Butterfly wing (Tirumala hamata) as imaged with both optical and leave scanning helium microscopy.* Credit: ANFF Materials node, University of Newcastle.

Miniaturising imaging devices with nanowires

> The success of this project has generated great interest in the scientific community, including a publication in the high impact journal *Nano Letters.*

Terahertz (THz) spectroscopy and imaging devices, which use high-frequency radio wave pulses to generate images, are widely used in applications such as materials analysis, security screening, and medical diagnostics. One of the most powerful THz techniques is known as time-domain spectroscopy, and is highly desirable for health and security applications due to the fact that it is non-invasive, safe, and low-energy.

To make time-domain spectroscopy devices more powerful and easier to manufacture, a reliable system for fabricating compact optoelectronics (devices to source and control light) is highly desirable. III-V semi-conductor nanowires are revolutionary optoelectroncis for this purpose. They have the potential to replace their bulk material counterparts as active THz emitting/detecting components due to their nanoscale structure and material properties.

III-V nanowires had not previously been developed and incorporated into the time-domain technique due to the challenges involved in material design, growth, and device fabrication.

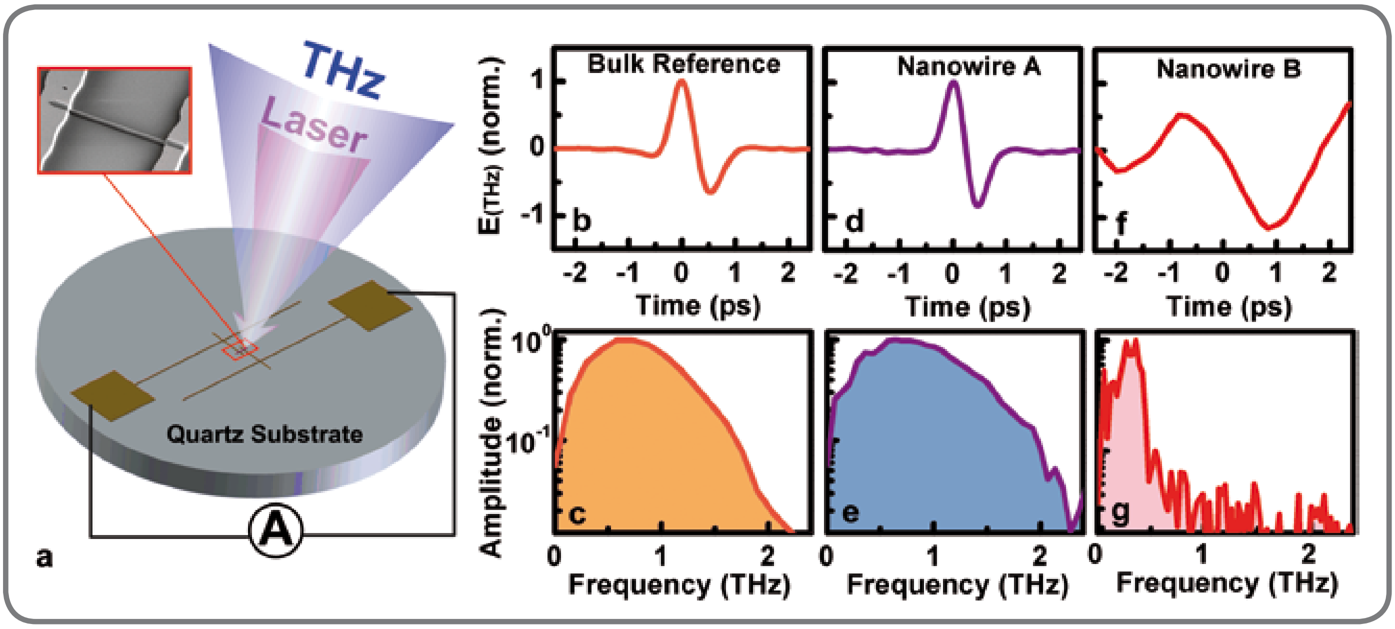
However, a team of researchers from the Australian National University in collaboration with the University of Oxford has recently succeeded in demonstrating III-V single nanowire THz detectors for time-domain spectroscopy for the very first time.

The fabrication process involved growing the nanowires in a Metal Organic Chemical Vapour Deposition (MOCVD) system and using conventional UV and Electron Beam Lithography (UV-PL and EBL) to pattern the electrodes on the nanowires. The detectors were then metallised using Electron Beam Evaporation, and Scanning Electron Microscopy (SEM) was used to study the structure of the nanowires and detectors. Much of this work was performed using the facilities of the ANFF-ACT node.

The resulting devices exhibited excellent sensitivity (when compared to traditional bulk detectors) and tunable bandwidth, proving their suitability for low-cost real-world devices that can provide the same information as research-grade machines.

The success of this project has generated great interest in the scientific community, including a publication in the high impact journal *Nano Letters** (with a second article currently under preparation) and a presentation at the American Institute of Physics congress. From an industry standpoint, it is envisaged that this technology could be applied to a low-cost 'lab-on-a-chip' system for studying small amounts of materials. Eventually, this could even lead to spectroscopy capabilities on smartphones and other small handheld devices.

**Peng, K. et al. Single Nanowire Photoconductive Terahertz Detectors. Nano Letters 15, 206-210, doi:10.1021/nl5033843 (2015).*



• *(a) A schematic diagram of the detector geometry and optical arrangement used in this work. (b) – (g) THz responses measured from a bulk InP receiver (b) (c); a single InP detector (d) (e); a single GaAs/AlGaAs nanowire detector (f) (g) in a terahertz time-domain spectroscopy system (Top: measured THz electrical field signal. Bottom: response spectrum)* Credit: Reprinted with permission from *Nano Letters* 2015 15 (1), 206-210 DOI: 10.1021/nl5033843. Copyright 2015 American Chemical Society.

New technologies to avoid the internet data capacity crunch

The optical fibre is the backbone of all global internet communication. Every day, 80 exabytes of data are transferred across optical fibres; this is the same as transferring the gigabyte equivalent of all movies ever made, every five minutes.

In simple terms, it's a lot of data. Due to the basic human desire to communicate, the internet data demand is exponentially increasing. By 2018, the total internet data demand is projected to have tripled with respect to 2013.

However, there is a fundamental limit to how much data can be carried across currently deployed single-mode optical fibres. This is known as the nonlinear Shannon limit, and is caused by optical nonlinearities intrinsic to the fibre design and material. As a result, new technologies are required to further expand the transmission capacity and avoid the capacity crunch. The most promising technology is space-division multiplexing.

The basic idea of space-division multiplexing is to either have multiple single-mode optical cores within a common optical cladding, or to use few-moded optical fibres. In both cases, the transmission capacity increases proportionally with the number of single-mode cores or the number of modes supported by the few-moded optical fibre, respectively.

Internet data demand is exponentially increasing, however there is a limit to how much data can be carried across currently deployed single-mode optical fibres.

Furthermore, space-division multiplexing brings significant improvements in cost per bit as well as energy efficiency due to a reduction in the number of discrete components in optical communication systems when compared to individual single-mode fibres. When using few-moded optical fibres, the challenge lies in the ability to selectively excite and detect the individual modes of the fibre. Researchers from telecommunications venture Modular Photonics have made inroads to doing just this.

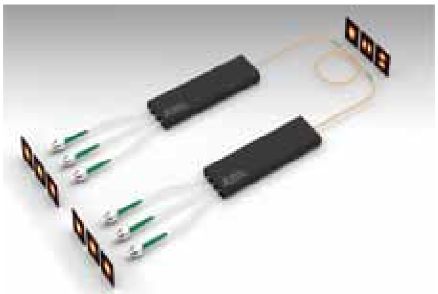


Illustration of Modular Photonics' multiplexor/demultiplexor components. The optical chips inside add and drop single mode channels to/from multi-mode transmission lines.
Credit: Nicolas Riesen, Modular Photonics.

Femtosecond Laser inscribed optical chip at the heart of the Modular Photonics components.
Credit: Simon Gross, Modular Photonics.

Modular Photonics have recently developed compact mode-multiplexers and demultiplexers suitable for future networks using few-moded optical fibres. The project has been undertaken using the facilities of the OptoFab node of ANFF, including glass processing, ultrafast laser inscription, optical assembly, and packaging facilities. The multiplexers take individual single-mode inputs and selectively convert them into the higher order modes of a few-moded fibre and vice versa. The devices are inscribed into a monolithic block of glass using ultrafast laser inscription, whereby a femtosecond laser is tightly focused into the bulk glass, inducing a localised and permanent modification of the substrate and creating optical waveguides.

The design of the multiplexers and demultiplexers takes advantage of the 3D capability of ultrafast laser inscription in order to achieve low losses, broad operational bandwidth and excellent mode-selectivity. This results in a highly scalable, compact and robust integrated photonic circuit. It is envisaged that optical components like these will be taken to market in the course of the next three years, as spatial division multiplexing becomes more common in high-bandwidth optical networks.

OptoFab is well placed to act as the foundry for future photonic chips, from the R&D phase to initial production runs.

Australian National University
cudos An ARC Centre of Excellence
Modular Photonics
MACQUARIE University SYDNEY·AUSTRALIA

Simon Gross – co-founder at Modular Photonics

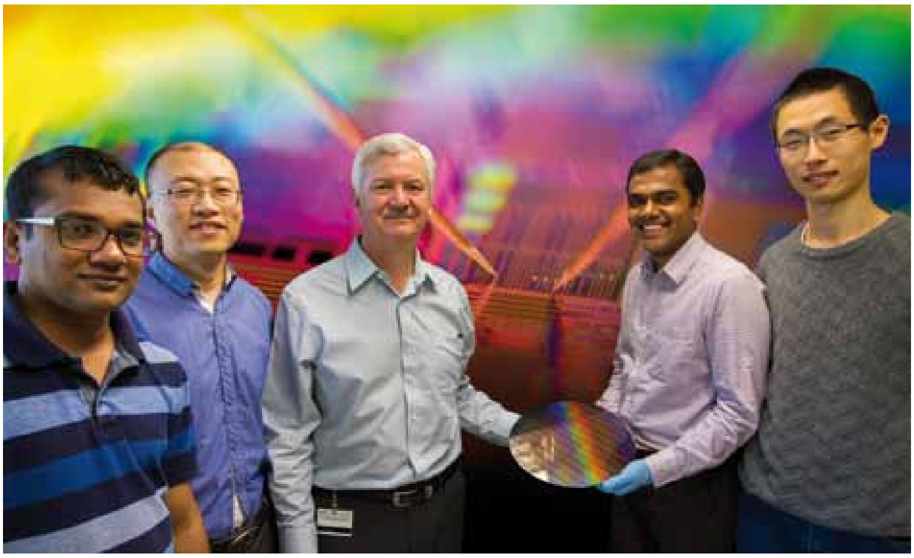
A collaboration between Macquarie University and the Australian National University seeded an idea for a device that would allow more data to be transmitted through an optic fibre.

Modular Photonics was subsequently founded by Dr Simon Gross and Prof. Mick Withford from Macquarie University (OptoFab Node Director), Dr Nicolas Riesen from the University of Adelaide, and Prof. John D. Love from the Australian National University.

The Sydney-based start-up successfully developed a prototype device tailored for the optical telecommunications industry, a '3D Integrated Mode Converter'. The business end of the device uses 3D waveguides inscribed inside a block of glass as a novel way to separate optical signals travelling down an optical fibre. The development and fabrication of the device relies on the nationally unique femtosecond laser capabilities at the OptoFab node of ANFF.

Although Modular Photonics is in its infancy, it has already generated interest from major communication equipment providers and leading research institutions in the field of optical communications. The venture has already generated sales in Europe and Japan.

www.modularphotonics.com



Low power oscillators for brain-inspired computing

The scalability, low operating power and high endurance of the oscillators make them ideal for the high-density non-boolean computing architecture that could make smartphones as powerful as supercomputers.

Non-boolean computer chips, which work more like the human brain than conventional computing architecture, have the potential to perform image and sound recognition faster and more accurately than current state-of-the-art computers. While conventional chips operate around the clock, non-boolean chips are event-driven and only operate when they need to. As a result, the real-time power consumption is orders of magnitude lower than current devices.

Oscillators are an essential component of these computer chips and are used to generate the periodic signals for storing information and recognising patterns. However, current oscillators use a device structure that is difficult to scale down for use in high-density non-boolean computer architecture.

Scientists at the Australian National University have recently developed oscillators that are suitable for use in non-boolean computer chips. The oscillators were fabricated using the Electron Beam Lithography (EBL) system and thin-film deposition tools at the ANFF-ACT. The novel, sandwich-like vertical structure takes advantage of the properties of ultra-thin functional oxides and can be easily stacked and replicated.

The scalability, low operating power and high endurance of the oscillators make them ideal for the high-density non-boolean computing architecture that could make smartphones as powerful as supercomputers. The research team is currently working to fabricate these oscillators at the nanoscale and link the individual elements to test their synchronisation; a fundamental factor for pattern recognition and information storage in non-boolean computing.

Researchers have now exponentially improved the optical quality of (Al)GaAs nanowires by encapsulating them in a metal cavity.

• *Sputter deposition system at ANFF-ACT.*

A metal cavity for brighter optoelectronics

Semiconductor nanowires are promising building blocks for next generation optoelectronic devices, such as lasers, LEDs, and solar cells. Their small size and wire-like shape results in a host of advantages for realising compact and more power-efficient devices, however, the optical quality of nanowires is greatly affected by the presence of 'dangling bonds'. Dangling bonds cause the surface of the nanowire to act as an electron sink, preventing the electrons from generating light and diminishing the nanowire's optical quality.

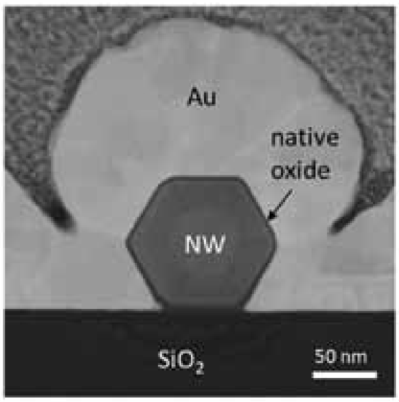
This problem is particularly apparent in gallium arsenide (GaAs) nanowires, which are very poor light emitters despite the fact that GaAs itself is an efficient light-emitting material. As GaAs is a technologically important material that is widely used, boosting the optical quality of GaAs nanowires is critical for the development of future optoelectrical devices.

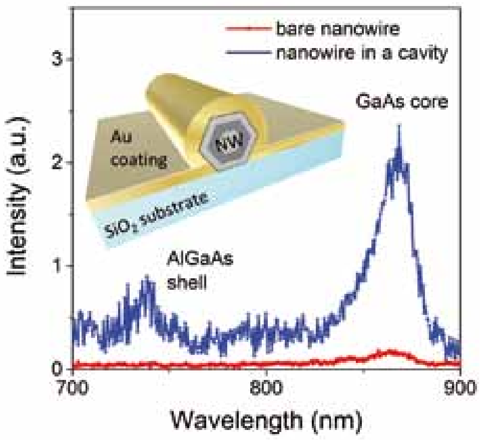
Researchers from the Australian National University discovered in 2013 that they could significantly improve the optical quality of GaAs nanowires by growing aluminium gallium arsenide (AlGaAs) shells around them. Building on that research, the team has now exponentially improved the optical quality of the (Al)GaAs nanowires by encapsulating them in a metal cavity.

Using facilities at the ANFF-ACT node, the team used computer modelling to define the design parameters for an omega (Ω) shaped metal cavity. They then grew the (Al)GaAs nanowires using Metal Organic Chemical Vapour Deposition (MOCVD), which is the method favoured by the semiconductor industry thanks to its scalability. The nanowires were transferred to a glass substrate and then coated with gold using sputter deposition to achieve the desired shape for the metal cavity. When assessed, the optical quality of the nanowires encapsulated in the cavity showed an order of magnitude enhancement in luminescence as compared to the as-grown nanowires.

These results surpass any improvements that have been achieved with more conventional methods. The cavity design can be adapted for different materials and can be used to enhance the luminescence of intrinsically poor optical materials.

Ultimately, the nanowire devices must be electrically (rather than optically) driven for practical implementation. Achieving this will now be the main focus for the research team, with the long term goal of creating energy efficient devices with optimum optical quality.





• *Left: Cross-section high angle annular dark field (HAADF) Scanning Transmission Electron Microscope (STEM) image of a GaAs core-AlGaAs shell-GaAs cap nanowire enclosed in a Ω-shaped cavity. A 4 nm-thick native oxide is formed between the nanowire and Au coating. Right: Photoluminescence spectra from (Al)GaAs nanowire with and without Au coating, measured under the same experimental conditions. Inset shows a schematic of the Ω-shaped cavity formed around the core-shell-cap nanowire.*

Developing more efficient and affordable solar cells

Silicon solar cells have captured 91% of the photovoltaic market due to their economic competitiveness. However, the efficiency of the best solar cells has stayed at around 25% for the last 15 years.

Cells made of materials in the third and fifth column of the periodic table (III-V materials) have reached efficiencies close to 45% but are prohibitively expensive. Researchers at the University of New South Wales have recently combined the best of both worlds: the affordability of silicon and the high efficiency of the III-V materials.

The research team, led by Prof. Allen Barnett and Dr Ivan Perez-Wurfl and working in collaboration with AmberWave Inc. and Veeco, achieved this by gradually changing the atomic spacing of the silicon substrate so that it matched the atomic spacing of the III-V materials, using germanium as an intermediary layer. AmberWave Inc. grew the germanium layers on the silicon substrate using Reduced Pressure Chemical Vapour Deposition (RPCVD), after which Veeco grew the III-V materials on top of the silicon-germanium layer using Metal Organic Chemical Vapour Deposition (MOCVD). This resulted in near-perfect layers of III-V materials.

Technologies at ANFF-NSW including photolithography, thermal evaporation, e-beam evaporation, wet chemical etching and device isolation were used to turn this material stack into working solar cells. Fabrication was completed at the University of New South Wales.

The most significant outcome of this project was the achievement of a world record efficiency for dual junction solar cells on silicon; a breakthrough technological development that takes the team one step closer to beating the long-held record efficiency of silicon solar cells. Current results indicate efficiency close to that of the best silicon solar cells on the market, and the team hopes to demonstrate solar cells with 26% forecasted efficiency in the near future. This work will contribute towards making photovoltaics an even more affordable, renewable and industrially competitive energy conversion technology.

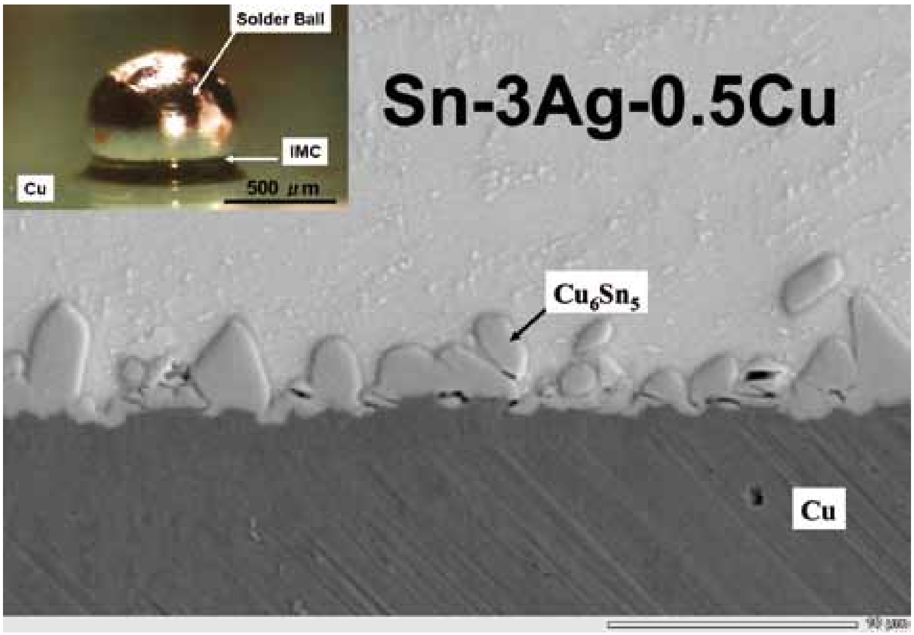
The most significant outcome of this project was the achievement of a world record efficiency for dual junction solar cells on silicon.

• *Ultra-high Efficiency Solar Cell Team at the School of Photovoltaic and Renewable Energy Engineering at UNSW.*

Taking lead out of electronic materials

Cu_6Sn_5 is of significant interest to the manufacturing industry as it is present in the majority of soldered interconnects, including those of future 3D electronic devices.

• *Electronic packaging.*



• *Cross-section SEM image for Ball Grid Array (BGA) solder interconnect.*

Electronic devices contain many internal connections between copper substrates and soldering materials. Historically, lead-based alloys have been used as the principal soldering material for this purpose, however, due to associated health risks, lead is no longer used in the manufacture of electronics.

Lead has been replaced with tin-based alloys containing several metallic components, including a compound known as Cu_6Sn_5. This compound is of significant interest to the manufacturing industry as it is present in the majority of soldered interconnects, including those of future 3D electronic devices.

During the soldering process, a fine layer of Cu_6Sn_5 forms spontaneously between the copper substrate and the solder itself. If cracks appear in this layer of Cu_6Sn_5 (when, for example, a mobile phone is dropped), the connection within the electronic device will fail. The chance of failure is increased substantially by any flaw or instability originating in the manufacturing process; therefore, the Cu_6Sn_5 must be mechanically and electronically sound to optimise device performance.

Cracks causing joint failure can form during soldering or during use of a product because the crystal structure of Cu_6Sn_5 changes as it heats and cools, resulting in expansion and contraction. Researchers from the University of Queensland and the ANFF-Q node have recently found that adding different metallic elements to the soldering alloy can stabilise the Cu_6Sn_5 and alleviate this issue. In particular, they have discovered that additions of zinc, gold and indium can help to minimise stresses caused by thermal expansion.

The team used ANFF-Q's high-precision Differential Scanning Calorimetry (DSC) equipment to detect the very small thermal changes that took place during soldering when different metals were included in the solder alloy. They mapped this information with diagrams that can now be used to improve processing technology and develop more resilient alloys.

The outcomes are not only of great scientific value, but will also influence the electronic packaging process and the designs of future joining materials, and other products containing Cu_6Sn_5.

The team's work with their industry sponsor Nihon Superior has produced four co-patents so far, and will play an important role in Nihon's current and future products.

Directing the self assembly of transistor components

A team of researchers from the University of Queensland and Intel Corporation have combined light-based techniques with self assembly to print nanoscale features approximately 5,000 times narrower than the width of a human hair.

The semiconductor industry, which has an annual turnover of over $300 billion, bases its growth on being able to fabricate computer chips with an ever-increasing number of transistors for greater computing power and power efficiency. This requires the precise manufacture of ever-smaller transistors, which now have dimensions in the nanoscale.

Conventional light-based fabrication methods rely on increasingly smaller wavelengths of light to manufacture devices, however these methods are reaching their limits of effectiveness.

One potential alternative is fabrication by self assembly, whereby researchers harness the guiding physics of a system to build nanoscale objects. By modifying the chemical structure and properties of individual components, scientists are able to direct how the components fit together into well ordered patterns and effectively 'direct' the self assembly process.

A team of researchers from the University of Queensland and Intel Corporation have combined light-based techniques with self assembly to print nanoscale features approximately 5,000 times narrower than the width of a human hair. Using these methods, they were able to overcome the limits of solely light-based techniques and take a step towards next generation transistors.

The researchers synthesised polymer molecules with properties ideal for self assembly. By directing the self assembly of the polymers, the team was able to print features less than 10 nanometres in size, which is far smaller than those achieved through light-based patterning alone. In addition, they have patented a methodology for improving the precision of patterns generated by light-based lithography, which will improve the performance of next generation computer processes.

The project utilised tools at the ANFF nodes in Queensland and the Australian Capital Territory, including Size Exclusion Chromatography, Spectroscopic Ellipsometry, Reactive Ion Etching, Electron Beam Lithography and Atomic Force Microscopy. Complementary characterisation methods were also carried out at the Centre for Microscopy and Microanalysis, the Queensland node of the Australian Microscopy and Microanalysis Facility (AMMRF) and at the Australian Synchrotron.

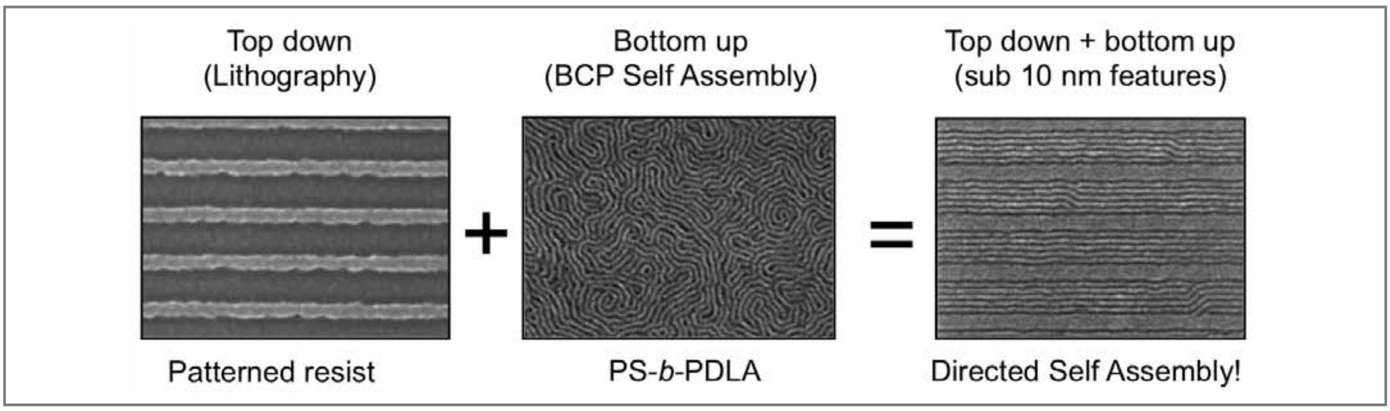
The resulting fabrication process is directly compatible with semiconductor fabrication methods, yet has a much higher resolution than current light-based systems. The outcomes of this project give Australia the chance to play a significant global role in developing processes for high end semiconductor manufacture.

The project was undertaken with the support of the Intel Corporation and the Australian Research Council (ARC) linkage scheme. Further work is also being undertaken in conjunction with Dow Chemical Company under an ARC Linkage Project to investigate other ways polymers can be used to improve the manufacture of semiconductors.

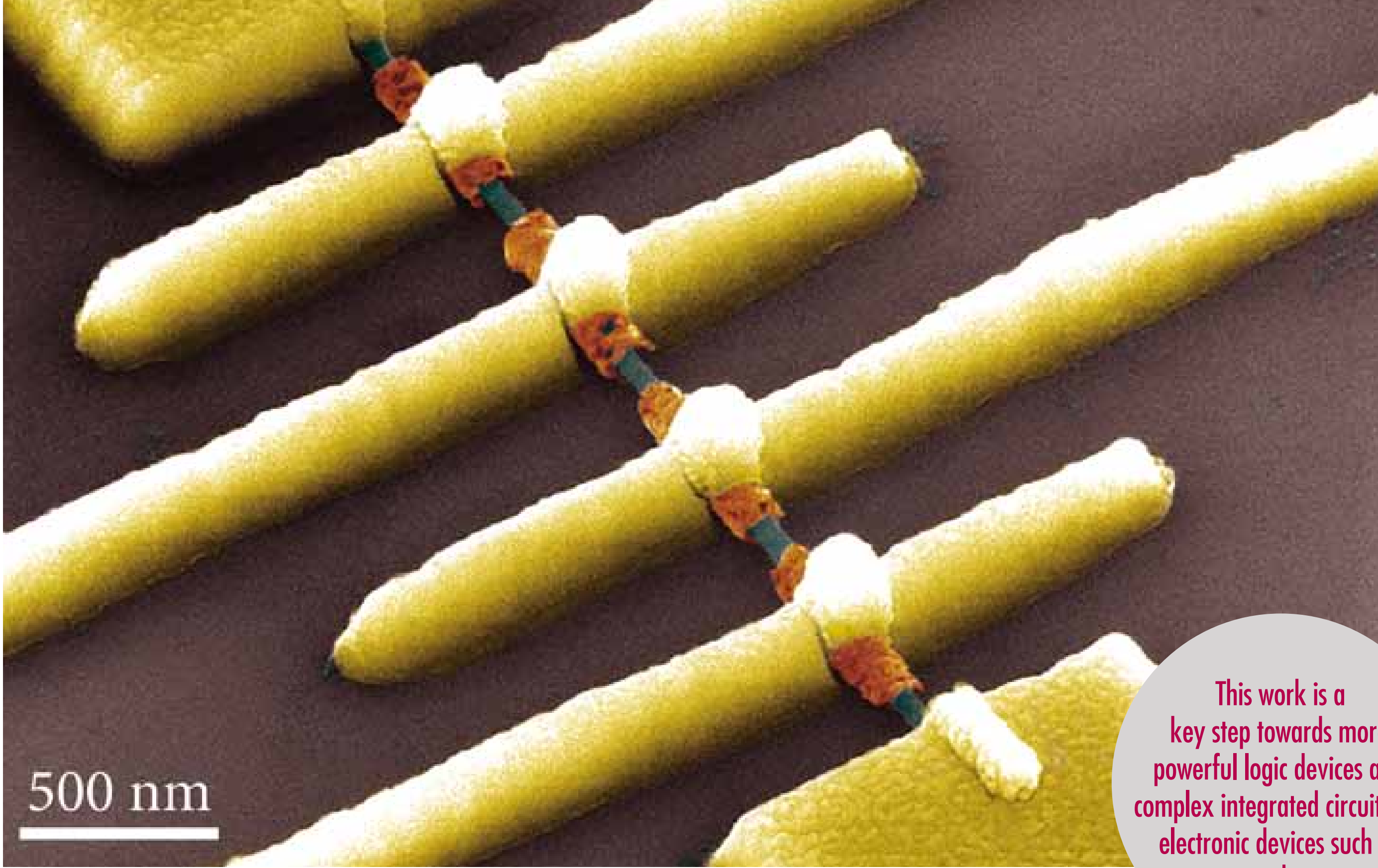
intel®

DOW CORNING

Keen, I. et al. Behavior of Lamellar Forming Block Copolymers under Nanoconfinement: Implications for Topography Directed Self-Assembly of Sub-10 nm Structures. Macromolecules 47, 276-283, doi:10.1021/ma4019735 (2014).



• *Directed self assembly for next generation semiconductor manufacture.* Credit: A.Prof. Idriss Blakey, AIBN, The University of Queensland.



This work is a key step towards more powerful logic devices and complex integrated circuits for electronic devices such as smartphones.

• *Scanning electron micrograph showing a horizontal nanowire transistor with four independent wrap gates.*
Credit: Adam Burke.

Nanowire transistors with multiple, independent wrap-around gates

The continued development of faster, smaller electronics depends on miniaturisation of the building block of modern devices: the transistor. A higher density of miniaturised transistors means more computing power for all devices containing computers, such as smartphones, cars, utility meters, and even some ovens.

The transistor acts as an electronically controlled tap for electrons, changing or amplifying the electric current as it passes from the 'source' through to the 'drain' within the device. The current is controlled by an electrode known as a 'gate'. When dealing with ultra-small transistors, the challenge lies in making gates that work effectively. The most effective gates – known as 'wrap-gates' – wrap all the way around the nanowire, however they are not easy to make for a nanowire sitting horizontally on a chip.

Researchers from the University of New South Wales and Lund University in Sweden have been working for several years to overcome this problem. They initially developed a technique for making horizontal wrap-gated nanowire transistors by taking semiconductor nanowires, which grow vertically from the substrate, depositing gate metal on the outside, and then knocking the nanowires over before making the rest of the device.

The team has now improved on their previous work by making a larger number of independently controllable wrap-gates on a single horizontal nanowire. This is a key step towards more powerful logic devices and complex integrated circuits for electronic devices such as smartphones. Electron Beam Lithography (EBL) technology at ANFF-NSW was used to precisely align the gates, interconnects and contact structures to the nanowire.

The outcomes of this research reveal a major scalability advantage for horizontal nanowire transistors when compared to their vertically-oriented cousins (which have previously garnered more interest from industry). In vertical nanowire transistors each gate requires the repetition of a complex set of fabrication steps, which add cost and reduce yield; whereas in the horizontal orientation, extra gates can be added without the extra cost. A publication in the high-impact journal *Nano Letters** cemented the significance of this project.

The project has implications for approaches to making large-scale circuits from nanowire transistors, particularly for electronics using 3D networks of nanowire transistors to maximise the density per unit of chip area. In basic terms, this is another step towards fitting more computation power into less space. The team will continue to work on more complicated nanowire-integrated circuits; research that will contribute to long term improvements for compact electronic devices.

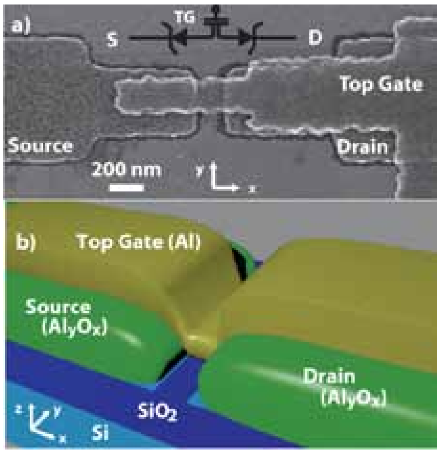
*Burke, A. M. et al. InAs Nanowire Transistors with Multiple, Independent Wrap-Gate Segments. Nano Letters 15, 2836-2843, doi:10.1021/nl5043243 (2015).

Low power logic

The modern transistors used in computer systems are consuming too much energy. High energy consumption, as well as being costly, leads to very high temperatures and makes it difficult to manufacture microelectronics that require transistors to be within a few nanometres of each other. By developing transistors with lower power consumption and cooler operating temperatures, enormous energy savings can be made and device efficiency can be improved.

To address these issues, researchers at the University of New South Wales have developed a new low-power transistor geometry in which the top gate electrode is self-aligned with the device channel and overlaps the source and drain electrodes. This geometry is based on tunnel processes, which use less energy and produce less heat than conventional transistors. It is also simple and cheap to produce. The devices were fabricated using capabilities at the ANFF-NSW node including etching, Electron Beam Lithography (EBL), and deposition.

Moving forward, the research team will focus on fabricating transistors with different materials including superconductors, which operate at temperatures low enough to transport current without producing heat. In their present form, the superconductor materials are not compatible with existing semiconductor manufacturing processes. Therefore, the team will aim to combine the low energy consumption properties of the superconductor materials with the well-understood properties of semiconductor materials to form cheap, energy-efficient and easily manufactured digital components. This project will provide a new tool for the development of low power, high end transistors for everyday use, as well as applications yet to be discovered in next generation electronics.



• *a) Scanning electron microscopy image of one of our three terminals (i.e. source (S), drain (D) and top gate (TG)) device, with the equivalent circuit diagram as an inset. b) 3D schematic of the device, outlining the self-alignment between top gate electrode and the channel/leads.*

The transistor geometry uses less energy and produces less heat than conventional transistors, and is simple and cheap to produce.

Purches, W. E. et al. A planar Al-Si Schottky barrier metal–oxide–semiconductor field effect transistor operated at cryogenic temperatures. Applied Physics Letters 107, 063503, doi:10.1063/1.4928589 (2015).

François Ladouceur – founder of Zedelef Pty Ltd

UNSW researchers François Ladouceur, Zourab Brodzeli and Leonardo Silvestri founded their spin-off company after realising the impact that the optical sensing network technology they were researching could have across a broad range of industries.

Their technology, which was initially developed during an ARC Linkage project to monitor high-power electricity lines, also had applications in mine monitoring, ocean monitoring, and oil and gas distribution. Following this realisation, Zedelef Pty Ltd was born.

Zedelef's technology is particularly relevant where a large number of sensors must be distributed over large areas in a hazardous environment. The company provides transducers that enable standard sensors to be read optically instead of electrically, together with the accompanying interrogation system.

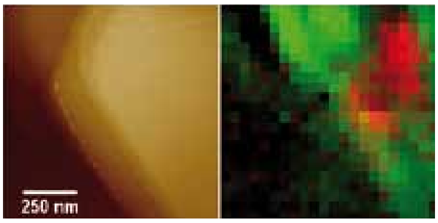
ANFF was instrumental in providing economical and practical access to the facilities needed to fabricate Zedelef's hybrid liquid-crystal optical fibre devices. ANFF's affordable fees replaced the capital-intensive equipment procurement that can be required when building a company, minimising risk and presenting an enticing picture for investors.

For more information, visit www.zedelef.com.au

ENVIRONMENTAL CHANGE

To respond effectively to different types of environmental change, we need to increase our understanding of what causes it, how we can predict and measure it, and how we should adapt and respond to its impact.

Nanoplate catalysts for a clean, green future



• *Atomic Force Microscope image showing part of a nanoplate (left) and the corresponding TERS map (right). Colour change from green to red represents a shift in the TERS peak, which indicates different nanoplate structure in the centre of the plate.* Credit: Ashley Slattery, ANFF South Australia, Flinders University.

To protect the environment, we have been forced to rethink how we produce energy and what we do with waste. Nanoplate catalysts have the capacity to change the way we respond to these issues by enabling wastewater purification, contaminant breakdown, and energy generation. As a bonus, they are also cheap to produce and are driven by visible light.

Nanoplate catalysts are small, plate-shaped crystals produced by chemical reactions in solution. They absorb visible light and that energy can then be used to perform reactions; for example, to split water molecules into hydrogen and oxygen, or to oxidise pollutants into non-toxic forms.

Understanding how these nanoplate catalysts are structured and what causes their behaviour will allow researchers to use them more effectively for real world applications. Study undertaken recently by a team at the University of Wollongong has achieved a comprehensive mapping of nanoplate catalysts at a higher resolution than ever before. In the process, the team confirmed that crystalline strain on the nanoplates is linked to the electronic structures that cause their catalytic activity; a long-held hypothesis among researchers.

Nanoplate catalysts have the capacity to change the way we respond to climate change by enabling wastewater purification, contaminant breakdown, and energy generation through water splitting.

The project used facilities at the ANFF-SA node including Tip-Enhanced Raman Scattering (TERS) microscopy, which was able to provide higher resolution imaging than conventional Raman imaging. Imaging the nanoplates with even higher resolution and exploring different plate geometries are avenues for further exploration, and work is currently underway to improve the detection sensitivity of the TERS technique.

The research team is currently working with overseas industry partners to commercialise the research outcomes. Fixating carbon emissions and building hydrogen-based solar farms on ocean shores that can produce low-cost energy without any secondary pollution, are a few potential directions for this venture.

Building a 'multi-colour' thermal camera

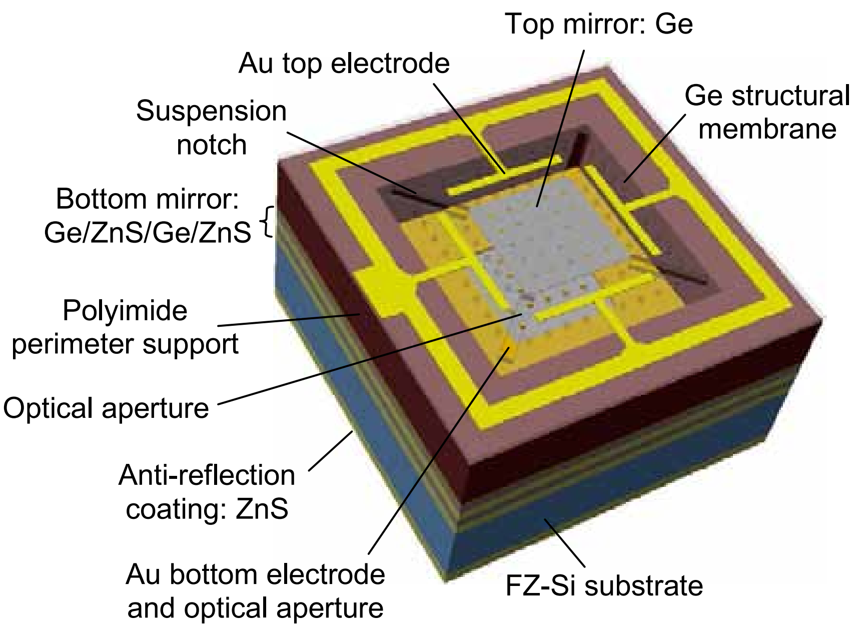
Optical spectrometers split light into its constituent colours and measure the 'colour content' of light. Measuring this colour content allows one to determine various properties, such as chemical composition or temperature, of any matter that the light has interacted with. For instance, if an object is said to be 'red-hot' its colour content is different to if it is 'white-hot'.

Infrared spectrometers perform the same function, but operate within the infrared spectrum, and examine the 'infrared colour content' of that light. Since all objects emit infrared light at much lower temperatures than the visible spectrum, measuring the infrared colour content gives an excellent measurement of the object's temperature.

A multispectral (multi-colour) thermal camera combines the benefits of imaging with spectroscopy, to produce an image that also contains infrared colour information. They are of great value for military applications (such as night vision and target identification) and also have potential to be used for real-time monitoring of atmospheric pollution and cloud imagery.

Current limitations preventing the widespread application of multispectral cameras are their size, weight, cost, and fragility. Miniaturising multispectral cameras could in theory be achieved using microelectromechanical systems (MEMS) principles, resulting in a low-cost on-chip multispectral camera, where the imaging element of the camera and the spectrometer are combined at the chip level to remove the need for bulky and expensive spectrometers outside the camera.

Infrared multi-colour thermal cameras are of great value for military applications and also have potential to be used for real-time monitoring of atmospheric pollution and global warming.



• *Schematic of the MEMS-based, tuneable LWIR Fabry-Perot filter: electrostatic actuation is used to vary the position of the suspended top mirror relative to the fixed bottom mirror, thus providing a means of controlling the cavity length and resulting in wavelength tuneability. The top membrane, except for the central mirror region, is drawn semi-transparent for illustration purposes only.* Credit: Mr Haifeng Mao.

The Microelectronics Research Group at The University of Western Australia, with support from the ANFF-WA node, have recently demonstrated exactly this. This team has effectively miniaturised the thermal spectrometer by developing a novel MEMS-based micro-spectrometer, and demonstrated its capability to detect emissions from objects near room temperature. They have also demonstrated survivability of these devices at the cryogenic temperatures needed for cameras detecting light in this band. This chip is now ready to be bonded to an imaging sensor in a thermal imaging camera for applications such as environmental monitoring.

The devices were fabricated using the facilities and tools of ANFF-WA, including plasma and thermal thin-film deposition, solvent wet-bench processing, i-line UV photolithography, reactive ion-etching and oxygen barrel ashing. Work is continuing, with the goal of integrating this technology into an imaging sensor chip to achieve a functional on-chip multi-colour thermal imaging sensor. This work has great potential for commercialisation and an upcoming industry partnership is expected to be announced soon.

• *The molecular beam epitaxy facility at ANFF Western Australia.*
Credit: The Microelectronics Research Group.

Lowering the cost of infrared

This new technique allows the production of high performance HgCdTe infrared devices at a fraction of the current cost.

Infrared detectors such as the micro-spectrometer described on the previous page, while smaller and more effective than existing technologies, are still expensive and require large and expensive cooling systems to operate. To date this has largely excluded infrared technology from being used for anything other than military applications.

The group at the University of Western Australia are tackling this issue.

At the business end of this MEMS device is material called HgCdTe (mercury cadmium telluride). It is used due to its high quantum efficiency in detecting infrared light and converting it into an electrical signal.

The fabrication process that has traditionally produced the best results involves growing HgCdTe onto an extremely expensive CdZnTe (calcium zinc telluride) substrate. This multilayer structure requires a cooling system for its operation at around 77K (around -196°C).

In an effort to lower the fabrication costs, researchers have made many attempts to find a suitable alternative substrate, with limited success. One of the main reasons that CdZnTe is so difficult to replace is that it is lattice-matched with HgCdTe, which in simple terms means that the building blocks of the two materials are similar enough to ensure growth of a stable structure. In comparison, other potential substrates with large lattice mismatch result in material growth with a high density of crystalline defects.

The ANFF-WA node team were able to develop HgCdTe 'barrier structures' on GaSb (gallium antimonide) substrates that allowed them to produce good quality HgCdTe infrared devices. This 'hybrid' concept combines unipolar n-type/barrier/n-type detector structures and semi-lattice-matched GaSb as substrates. Significantly, they are lower cost, and allow higher infrared detector operation at temperatures that do not require cooling.

The prototype devices were built using Molecular Beam Epitaxy (MBE) to grow HgCdTe materials onto the novel substrates. The main challenge faced by the research team was controlling the MBE growth process and achieving quality epitaxial material throughout all the layers. The optimisation of growth procedures as well as device structure is currently underway, with test devices being designed, fabricated and assessed.

HEALTH

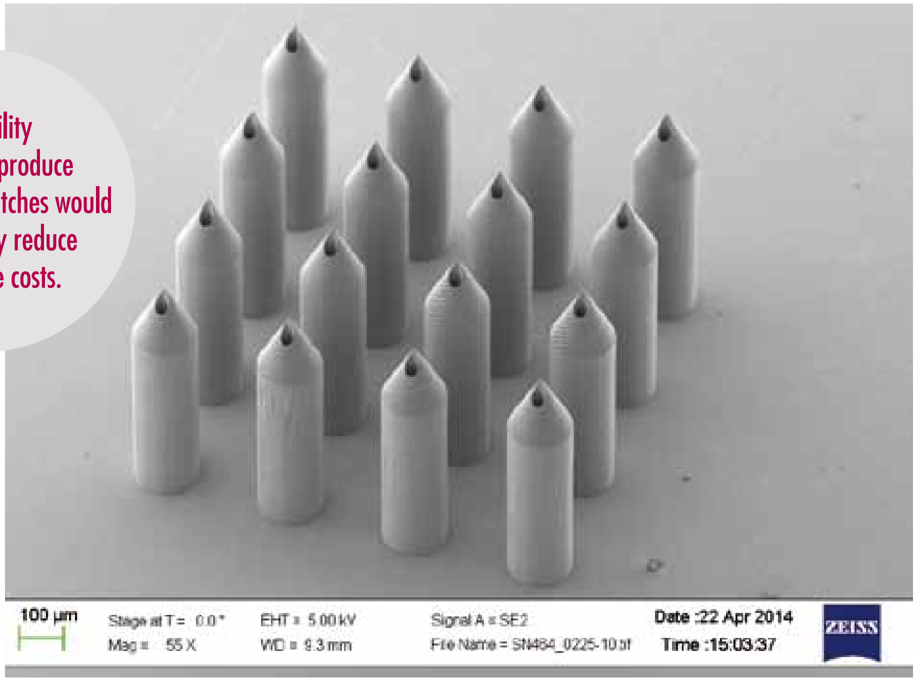
The science sector in Australia has a responsibility to draw on its wealth of knowledge and technology to improve health outcomes for the wider community. Health research in ANFF nodes around the country is developing innovative new ways to detect, treat and prevent diseases.

Taking the sting out of blood collection

Needles for blood tests and drug injection strike fear into the hearts of many. The good news is that this unpleasant process might not be a necessary evil for much longer.

> **The ability to cheaply produce microneedle patches would dramatically reduce healthcare costs.**

Researchers from the University of New South Wales have recently used 3D printing technology to fabricate a template for microneedle patches. The patch is designed using computer-aided drafting software, and then printed using the Nanoscribe™ 3D printer at the ANFF-Q node. The resulting printed template is used to mould a microneedle patch using medical grade plastics.



• *Microneedle patch array.* Credit: Zahra Faraji Rad, PhD Student, University of New South Wales.

The microneedle patch will allow patients to take a blood sample themselves, without the need for a doctor or nurse. The patch is 2.1mm x 2.1mm and, most importantly, the process is painless. The patch contains 16 microneedles designed with precise geometries that passively draw fluid from beneath the skin through capillary action.

Using 3D printing technology allows the researchers to print 3D geometries at a sub-micron resolution. This project is the first time that 3D printing technology has been applied to microneedle patch manufacture, and has resulted in a novel microneedle design that could replace the hypodermic needle for many applications. The ability to print the template and use it to mould multiple replica patches will significantly reduce manufacturing costs.

Cheaply produced microneedle patches, particularly when coupled with cheap blood analysis kits (which the team plan to develop in the future) would dramatically reduce healthcare costs by decreasing reliance on trained medical personnel and pathology services. Eventually, it is envisioned that blood analysis could take place inside the device itself.

The research team have partnered with Australian plastics manufacturer Romar Engineering and the Innovative Manufacture Cooperative Research Centre to realise the potential of this project.

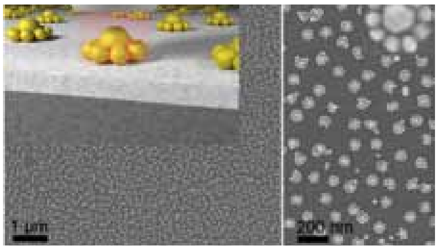
Nano-flowers for molecular sensing

Neighboring nanoparticles and the tiny gaps between them can give rise to some unique optical effects. One of these unique properties is that due to their size, the particle clusters can interact with, and in some cases dramatically amplify, light in ways that larger objects cannot.

The amplification or resonance properties of these particle clusters boost light intensity exponentially, allowing researchers to use techniques such as Surface Enhanced Raman Scattering (SERS) microscopy to detect target molecules with single molecule resolution. This capability offers promise as a sensing platform where minute quantities of a target are present, such as explosives residue or cancer markers in blood.

A team of researchers led by Associate Prof. Udo Bach from CSIRO have found that when spherical nanoparticles are arranged into flower-like clusters with multiple gaps (1/10,000 the thickness of a human hair), the amplification properties of the nanoparticles can be further enhanced.

In order to guide the assembly of these clusters, the team attached DNA to gold nanoparticles to give them a negative charge. Small glass surfaces were given a positive charge, after which the glass was placed into the gold particle solution, enabling a regular distribution of particles on the surface. DNA requires two different parts to form a double helix – the DNA on the surface particles contains one such part, while a solution of smaller particles provides the other. When the glass is placed into the solution with the smaller particles, the DNA comes together to form a double helix and connects the smaller particles to the larger ones, leading to spontaneous formation of the flower-like clusters.



• *Schematic representation of the nano flowers focusing incoming light in the gaps (glowing red dots). Overview SEM image on the left and zoomed-in views of the structures on the right showing the nano flower arrays.*
Credits: Soon Hock Ng, Yuanhui Zheng.

The assembly of these flowers was carried out in the biochemistry laboratory at the Melbourne Centre for Nanofabrication (MCN) in the ANFF-Vic node, while the progress and results were monitored using MCN's UV-Vis, SEM and AFM tools.

In comparison to commercially available SERS sensor chips, the flower clusters have proven superior in terms of signal intensity and reproducibility. Also noteworthy is the fact that protocol required for creation of these complex 3D structures is remarkably simple.

Besides the improvements in molecular sensing, the techniques developed in this project may be used to control the assembly of nanoparticles of various materials, and therefore applications are envisaged in processes such as catalysis. This is particularly attractive in times where renewable energies and processes like water splitting are of high interest.

Future stages of the project aim to continue in the same vein, as electrostatic forces can be used to assemble nanoparticles in pairs. Similar hotspots to those present in the flower structures can be produced in an even simpler way, while the effect of the size and the material of the nanoparticles on performance may help to unlock new applications for such structures.

Nanoparticles can be used as a platform for ultra-sensitive molecular sensors with the potential to detect minute quantities of molecules used in explosives or cancer markers in blood.

• *First prototype of the optrode. Covering an area of 10mmx10mm, the optrode consists of a silicon back where circular gold electrodes of various sizes have been deposited – these also act as mirrors. Covering the mirrors is a layer of liquid crystals (5 micron thickness) protected by a transparent electrode (ITO covered glass plate).* Credit: Courtesy of Mr Josiah Firth.

Improving the brain-machine interface

Understanding how biological neural networks operate is of fundamental importance in biology for conditions ranging from epilepsy to visual impairment. Brain-machine interface (BMI) technology gives scientists a direct connection with the brain, allowing them to record neural responses and reveal emergent behaviours that are impossible to tackle when focusing on single neurons.

Existing BMI sensors based on electrodes are limited in functionality and performance due to a number of technical challenges. One of these challenges is the sheer scale of the human brain; BMI sensors have up to a few hundred electrode channels which are tasked with interacting with many billions of brain cells. Based on this concept, the number and density of electrodes would need to increase exponentially to produce a more functional interface between technology and biology.

Professors François Ladouceur and Nigel Lovell from the University of New South Wales have taken a different approach to improving BMI technology. They have recently succeeded in producing a proof-of-concept optrode by using a new class of liquid crystals developed at the ANFF Materials node in Wollongong. These liquid crystals can react to the presence of minute electric fields, such as those produced by neural action potentials found in living tissues, and their reaction can be monitored using polarised light. Hence, it is possible to optically 'see' the neural activity when the optrode (together with the living tissue) is put under a microscope. This ability to capture real-time images of the neural behaviour obviates the need for endless numbers of electrode wires.

The first prototype of the optrode covers an area of 10mm x 10mm and consists of circular gold electrodes of various sizes deposited on a silicon base. The electrodes, which also act as mirrors, are covered by a thin layer of liquid crystals protected by a transparent electrode.

> **Realised at its full potential, this technology would enable researchers to map the collective behaviour of neural networks such as those found in cardiac tissues, brain tissues or the retina.**

This project represents a collaboration between the electrical and biomedical engineering departments of the University of New South Wales. The sensing technology was developed by Prof. Ladouceur, while its application to the biomedical field is led by Prof. Lovell. A significant amount of the fabrication process was undertaken at the ANFF facilities at the University of New South Wales and the University of Queensland, and new breeds of liquid crystals are currently being developed at ANFF Materials facilities at the University of Wollongong.

Over the coming months, new fabrication processes will be developed with the goal of allowing interaction with living tissue. To achieve this, each electrode will need to have electrical contact with the living tissues through the silicon layers.

Realised at its full potential, this technology would enable researchers to map the collective behaviour of neural networks such as those found in cardiac tissues, brain tissues or the retina. Understanding this collective behaviour – or system level behaviour – is of fundamental importance for the understanding of such tissues and could be used in very practical circumstances such as assessing the impact of new drug delivery mechanisms.

Ryan Pawell – founder of indee™

Ryan Pawell didn't like the way the healthcare system worked, so he decided start a company focused on technology that would make curative therapeutics safe, effective and affordable for all.

The result is indee™, a technology stage company currently in the process of validating Ryan's gene delivery device for therapeutic development.

This year Ryan has gone from a PhD student user and familiar face around ANFF Nodes, to a Silicon Valley entrepreneur whose technology has attracted many hundreds of thousands of dollars. indee™ uses ANFF facilities for device prototyping and networking support, with further potential research and development projects currently in the pipeline.

"Our technology potentially enables millions of people to be safely treated for diseases like cancer and HIV at low market prices, effectively democratising healthcare," said Ryan.

When device validation is achieved, indee™ will work towards clinical development.

"We would like to develop, market and sell our own therapeutics so that we can control pricing and allow more people to access this technology," said Ryan.

Gene therapy for the masses

Imagine a platform that made gene therapies accessible and affordable for the tens of millions of people burdened by disease each year. It would be a game-changer in the world of healthcare, and it is the aim of research being undertaken by scientists now at indee™ in San Francisco.

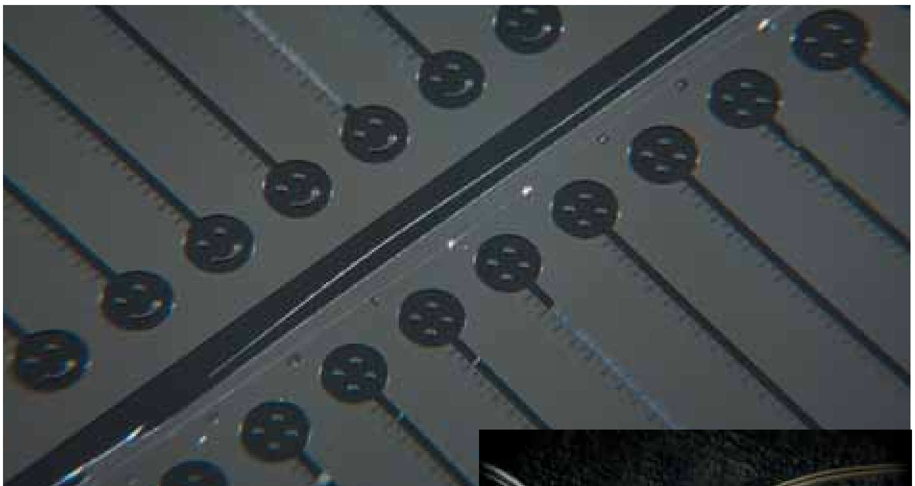
Lead researcher Ryan Pawell and his team have previously developed and published innovative methods for manufacturing and verifying microfluidic devices (a project featured in the 2013 ANFF Casebook and presented at the 2014 ANFF Showcase). In their latest project, they have used those devices to successfully deliver DNA to cells without causing cell death.

Gene delivery was tested in HEK293 cells using a membrane impermeable dye, DNA molecules and GFP plasmids. The microfluidic device allows precise cell processing, and all of these materials were delivered without causing cell death using a microfluidic technology that is cell-size independent. These exciting results – which have not been achieved by other microfluidic devices with similar aims – suggest that this technology could be ideal for therapeutic manufacturing.

In a practical setting these devices could be used by medical professionals in hospitals, changing the way we treat diseases such as cancer, HIV and neurodegenerative disorders.

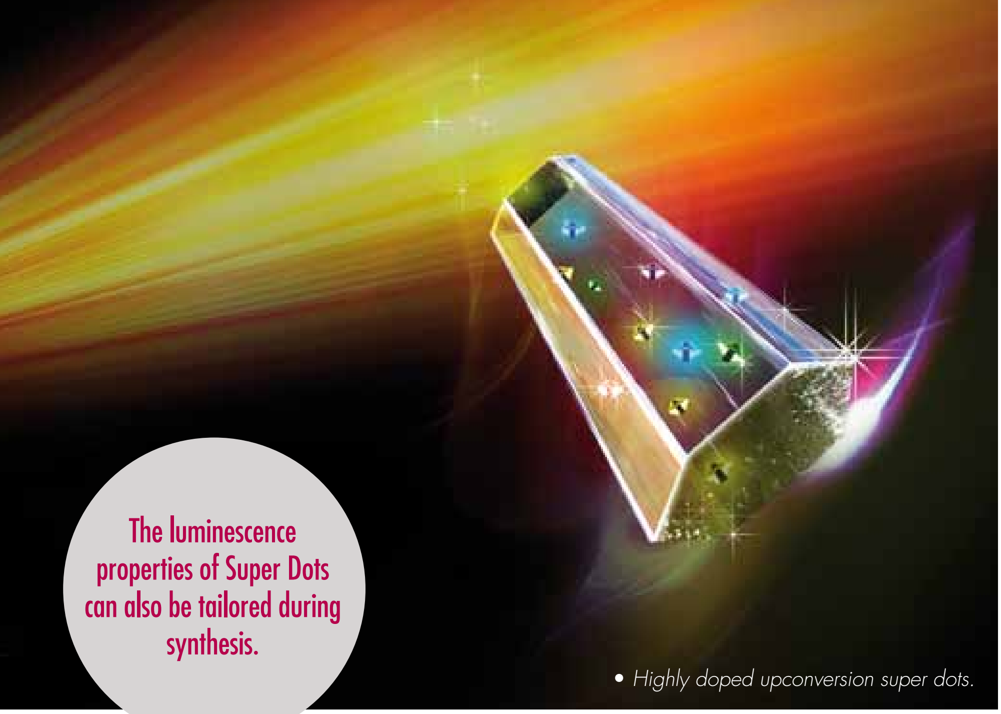
In a practical setting these devices could be used by medical professionals in hospitals, changing the way we treat diseases such as cancer, HIV and neurodegenerative disorders. Blood or bone marrow would be drawn from a patient and the device would isolate white blood cells and deliver DNA to those cells. The cells would then be injected back into the patient.

The project is now in the prototype and data validation stage, with the next round of devices being fabricated by the ANFF-SA node, the ANFF-Q node, and Bandwidth Foundry. Support for the project is also coming from venture capital fund SOSV, IndieBio, and NSW Health.



• *Microfluidic gene delivery designs shown to successfully deliver DNA to cells.* Credit: Warren McKenzie.

• *Microfluidic gene delivery designs shown to successfully deliver DNA to cells.* Credit: Warren McKenzie.



The luminescence properties of Super Dots can also be tailored during synthesis.

• *Highly doped upconversion super dots.*

• *Dayong Jin and Bradley Walsh accepting their prize.* Credit: Daniel O'Doherty.

Super Dots! Finding the needle in the haystack with the help of nano-flashlights

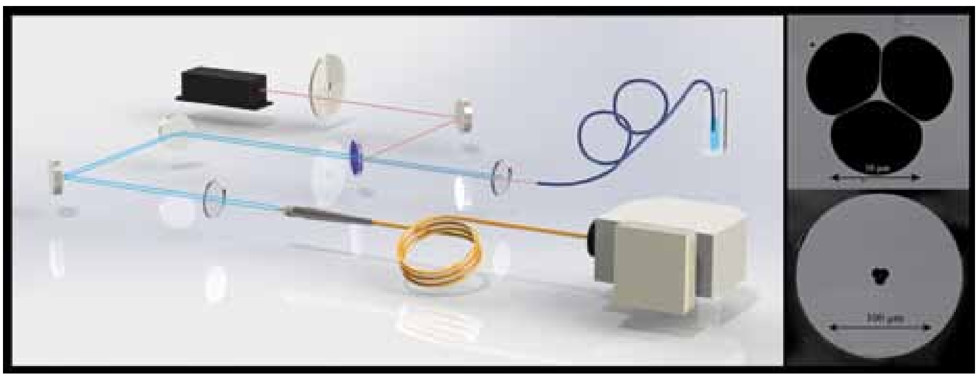
Imaging and sensing using targeted fluorescent markers is playing an increasingly important role in fields such as bio-chemistry and nano-medicine, as well as security and traceability. To this end, a team of researchers from Macquarie, Adelaide – and now the University of Technology Sydney and the University of South Australia – have developed some of the world's brightest and most versatile upconversion nanocrystals. The team has also demonstrated a sensing platform, capable of single molecule detection, by using the nanocrystals in a micro-structured optical fibre dip-sensor fabricated at facilities supported by the OptoFab node of ANFF.

Dubbed 'Super Dots!' these nanocrystals are synthesised with rare-earth elements, which give them their unique optical properties. Recently, Super Dots based on Thulium and Ytterbium have been demonstrated to be highly luminescent 'nano-flashlights' that can be readily functionalised with antibodies and other functional groups for the targeting of specific cells and molecules. The luminescence properties of Super Dots can also be tailored during synthesis, for example by changing the Thulium concentration, which leads to the potential for 'optical bar-coding' of multiple targets in a complex biological system.

The potential of highly sensitive sensing and detection using Super Dots has been demonstrated in a platform enabled by suspended core microstructured fibre. In this type of optical fibre, light being carried in the core strongly interacts with the medium that has infiltrated the tiny capillaries surrounding the core. This can act as a dip sensor which can detect minute concentrations of targeted molecules within tiny volumes of fluid. In fact, a single Super Dot nano-crystal can be excited and detected in this sensor. The nature of the fibre dip sensor also means sensing and detection has the potential to be done in vivo.

This body of work received the 2015 Eureka prize for Interdisciplinary Scientific Research as the research draws on expertise fields such as material chemistry, optical physics, nanotechnology, biotechnology, computational modelling and instrumentation engineering. See more at: http://australianmuseum.net.au/2015-eureka-prizes-winners

The Super Dots team is led by Prof. Dayong Jin from the University of Technology Sydney and Macquarie University; Prof. Tanya Monro from the University of South Australia and University of Adelaide and Prof. Bradley Walsh from Minomic International and Macquarie University. The work is being carried on by the ARC Centre of Excellence for Nanoscale BioPhotonics.



• *Detection of single upconversion super dots in microstructured optical fibre.*

Using nanotechnology for regenerative medicine

Imagine being able to grow new dental tissue in a cavity instead of getting a filling? Using tissue engineering, it may soon be possible to 'grow' new biological tissues on a porous scaffold, using a patient's own cells.

Although this is an area that is advancing quickly, there are still significant challenges to be overcome. One of these is design and growth of tissues that can mimic blood vessels and capillaries in terms of the movement of oxygen and nutrients and the removal of waste. Another issue is that capillary shapes are usually established using polymer materials, which are then discarded to reveal the capillary pattern. Ideally, this wastage should be minimised.

A team of scientists from the University of Sydney and the Oregon Health and Science University in Portland, Oregon, have now designed a porous scaffold structure for the growth of tissues with maximised cell survival and nutrient supply. The project uses a streamlined process and is specifically focused on the growth of dental tissue.

Initial computer simulations guided the design of the scaffold structure and was used to predict outcomes. The

• *Comparison between the mask pattern (left) with the hydrogel scaffold (right).* Credit: Giada Di Giacinto Barabaschi.

design was laser printed on a chrome/soda mask at Bandwidth Foundry, in the OptoFab node of ANFF, and evaluated for use in the manufacturing of a hydrogel scaffold. The structure was then tested with a cell culture,

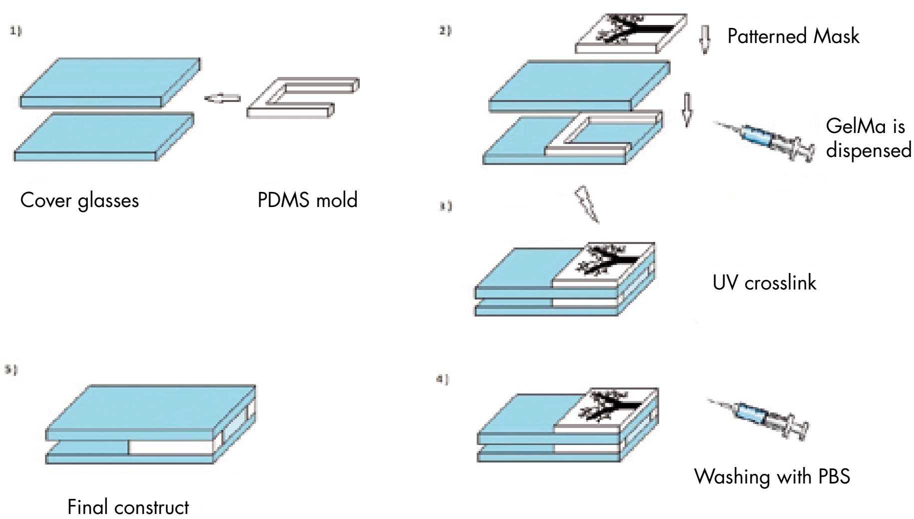
Tissue engineering has enormous potential for safely regrowing diseased or damaged tissue using the patient's own cells.

which confirmed the design's viability.

Using the laser printing process to create a template for the hydrogel structure is a simple, cheap and reproducible approach, and is faster than previously used methods. The structures designed by the research team are also more successful in keeping cells alive. The key to this success is optimising the pattern for cellular migration and viability.

The area under the mask only requires a quick wash to remove the excess hydrogel solution, which minimises wastage during the fabrication process. Having control over the replication of the pattern based on the initial mask also means that microchannels can be reliably constructed.

Tissue engineering has enormous potential for safely regrowing diseased or damaged tissue using the patient's own cells. The researchers will continue to develop this technology with a specific focus on bone and tooth tissue, however this technology could be used as a model for a range of future projects.



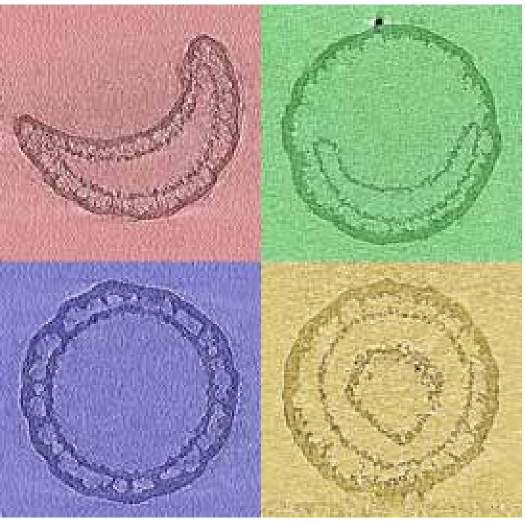
• *Scaffold fabrication process.* Credit: Giada Di Giacinto Barabaschi.

Delivering drugs directly to cells using nanoparticles

Delivering drugs directly into target cells offers exciting possibilities for the treatment of disease. A research team from the Australian Institute for Bioengineering and Nanotechnology, based at the University of Queensland, has developed hollow, mesoporous carbon nanoparticles that can successfully deliver large biomolecules into cells, making them promising nanocarriers for medical applications.

The researchers developed a novel method for preparing the nanoparticles through a facile and surfactant-free approach. Using this process, the researchers were able to control the particle size, pore size and structure of the nanoparticles.

As the particles were too small to be observed with a conventional optical microscope, a confocal microscope at the ANFF-Q node was used for observations. The particles were loaded with Oligo DNA molecules, labelled with a cyanine dye and incubated with target cells, after which cellular uptake was evaluated.



• *We report a new surfactant-free sequential heterogeneous nucleation pathway to prepare mesostructured hollow carbon nanoparticles. This strategy relies on two polymerisable systems, i.e. resorcinol-formaldehyde and tetraethyl orthosilicate, each of which undergoes homogeneous nucleation and particle growth. By controlling the polymerisation kinetics of two systems when mixed together, sequential heterogeneous nucleation can be programmed leading to monodispersed and mesostructured hollow carbon nanoparticles with large mesopores, controllable mesostructures (bi- and triple-layered) and rich morphologies (invaginated, intact and endo-invaginated spheres).*

Future work will involve loading the nanoparticles with anti-cancer medication so that the therapeutic effect of delivery can be evaluated.

By studying the performance of nanoparticles with different shapes and sizes, the team was able to confirm for the first time that those with an invaginated structure (whereby one side of the sphere is shrunken inwards) show a better compatibility with blood than those with intact structures. It was also found that pristine hollow carbon nanoparticles with large pore size and high volume demonstrate a high biomolecule loading capacity and are able to successfully deliver biomolecules into cells. The high uptake means fewer carbon nanoparticles are required for drug delivery in practical scenarios. The results of this project were published in the scientific journal *Chemistry of Materials**.

Future work will involve loading the nanoparticles with anti-cancer medication so that the therapeutic effect of delivery can be evaluated. This research has paved the way for the mass production of carbon nanoparticles with optimum drug delivery capabilities.

**Zhang, H. et al. Self-Organized Mesostructured Hollow Carbon Nanoparticles via a Surfactant-Free Sequential Heterogeneous Nucleation Pathway. Chemistry of Materials 27, 6297-6304, doi:10.1021/acs.chemmater.5b01993 (2015).*

Professor Mark Kendall – founder of Vaxxas

Professor Mark Kendall leads a multidisciplinary research group from the Australian Institute of Bioengineering and Nanotechnology at the University of Queensland (UQ).

Working alongside ANFF-Q, the group developed the Nanopatch technology, a next generation vaccine delivery platform providing a needle-free, safe and cost effective alternative to traditional vaccinations.

Professor Kendall developed the Nanopatch technology with the support of ANFF-Q facilities and personnel. Advanced instruments such as the deep reactive ion etcher, photoplotter, hot embosser and soft lithography suite were used to fabricate the microneedle arrays used in the technology.

Vaxxas was established to commercialise their technology in 2011 with $15 million in venture capital funding – one of Australia's largest series A investments in a start-up. Earlier this year they raised an additional $25 million in a series B round.

Investors so far include OneVentures, Brandon Capital Partners, The Medical Research Commercialisation Fund and HealthCare Ventures LLC. Vaxxas' plans include partnering with different vaccine companies to achieve safe, effective vaccine delivery in their particular disease areas of interest; potentially improving the lives of millions.

Professor Kendall is CTO of Vaxxas and remains an academic at UQ.

For more information, visit www.vaxxas.com www.anff.org.au