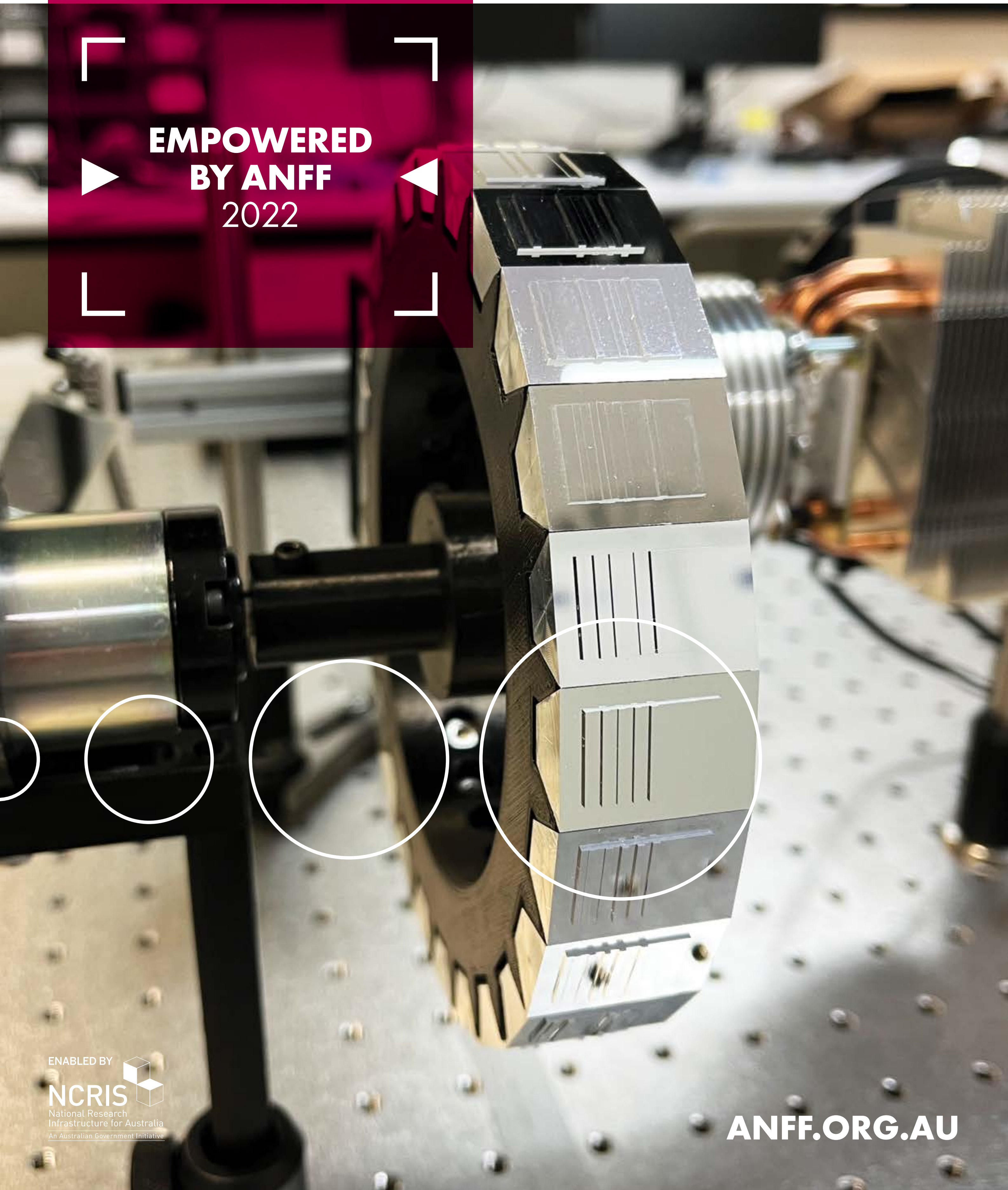
THE AUSTRALIAN NATIONAL FABRICATION FACILITY

ANFF

EMPOWERED BY ANFF
2022



ENABLED BY
NCRIS
National Research
Infrastructure for Australia
An Australian Government Initiative

ANFF.ORG.AU

ANFF IN 2021|22

In the last year (2021-22), ANFF has continued to experience the disruptions of the previous year, with operating impacts from COVID variants, supply chain difficulties and sporadic travel restrictions. Yet, despite all of this, ANFF has continued to maintain state-of-art offerings of micro and nanofabrication infrastructure to support thousands of researchers from the public and private sectors countrywide.

The Board and the ANFF community were delighted to welcome the appointment of ANFF's third CEO, Dr Jane Fitzpatrick. She has set about working with the ANFF Nodes on the three pillars of ANFF's Strategic Plan: maintaining the quality of its fabrication offerings; capturing the benefits for Australia of R&D supported in its facilities; and ensuring that Australia can strengthen the development of sovereign manufacturing capacity in appropriate areas.

In April 2022, the Commonwealth Government released the 2021 National Research Infrastructure Roadmap outlining the Research Challenges to be faced by Australia, including *Frontier Technologies and Modern Manufacturing*. With a national recognition of the importance of nanofabrication, ANFF will continue to pursue excellence in supporting a broad spectrum of R&D, leading to outcomes of the sort described in this Casebook. Thanks are particularly due to the Node Directors, Facility Managers and technical specialists who enable ANFF to support innovative research; ANFF's member universities and CSIRO, all of which provide financial and moral support.

The executive group in ANFF's national office has been strengthened to provide greater outreach capability to Australian industry and participation in the path to commercialisation of promising research outcomes.

These are exciting times and I thank all in the ANFF community for their stellar efforts to secure Australian leadership in addressing significant R&D challenges facing the world, so well captured in CSIRO's recent report *Seven Megatrends that will shape the next 20 years*.

Emeritus Professor Chris Fell AO FTSE
ANFF Chair

Happy 15th Anniversary ANFF and what an incredible year ANFF has had!

Looking back across the last 12 months we can see changes, achievements and new initiatives that have been built on the solid base that ANFF has created through its 15 years in existence.

The ANFF network has continued to perform strongly with numbers of users and hours of use achieving their targets. In addition, a jump in reported industry usage points to the growing awareness of how ANFF can accelerate the development cycle for vast arrays of new technologies.

This year we have rounded out the HQ team with six new recruits covering operations, client engagement, commercialisation and communications. This expanded team, located across the country, has brought new energy, ideas and skills that are now available to assist our ever-widening user base. The Client Engagement Team are a key part of ANFF's strategy to find ways to ensure people can find us when we can provide the solutions they need. In addition, the ANFF-C platform, now led by John Morrison, has started to provide funds to help lower the barrier to commercialisation for technologies that have been born of the ANFF tools. With this support we aim to help these promising innovations get one step closer to the goal of being on the market.

I would like to commend our staff for all their efforts throughout this challenging year. Once more they have excelled and been the foundation of our success.

The strong performance of ANFF shows that we empower research, development and commercialisation across the national priorities. The NRI Roadmap has highlighted some of the opportunities that lie ahead of us and with the strength of the network, the experts that we house and the leadership we bring, this organisation stands ready to have a greater impact on Australia's success than ever before.

Dr Jane Fitzpatrick
ANFF CEO

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

ANFF

Australian National Fabrication Facility Ltd
151 Wellington Road
Clayton VIC 3168
T: +61 3 9902 9619
E: info@anff.org.au
www.anff.org.au

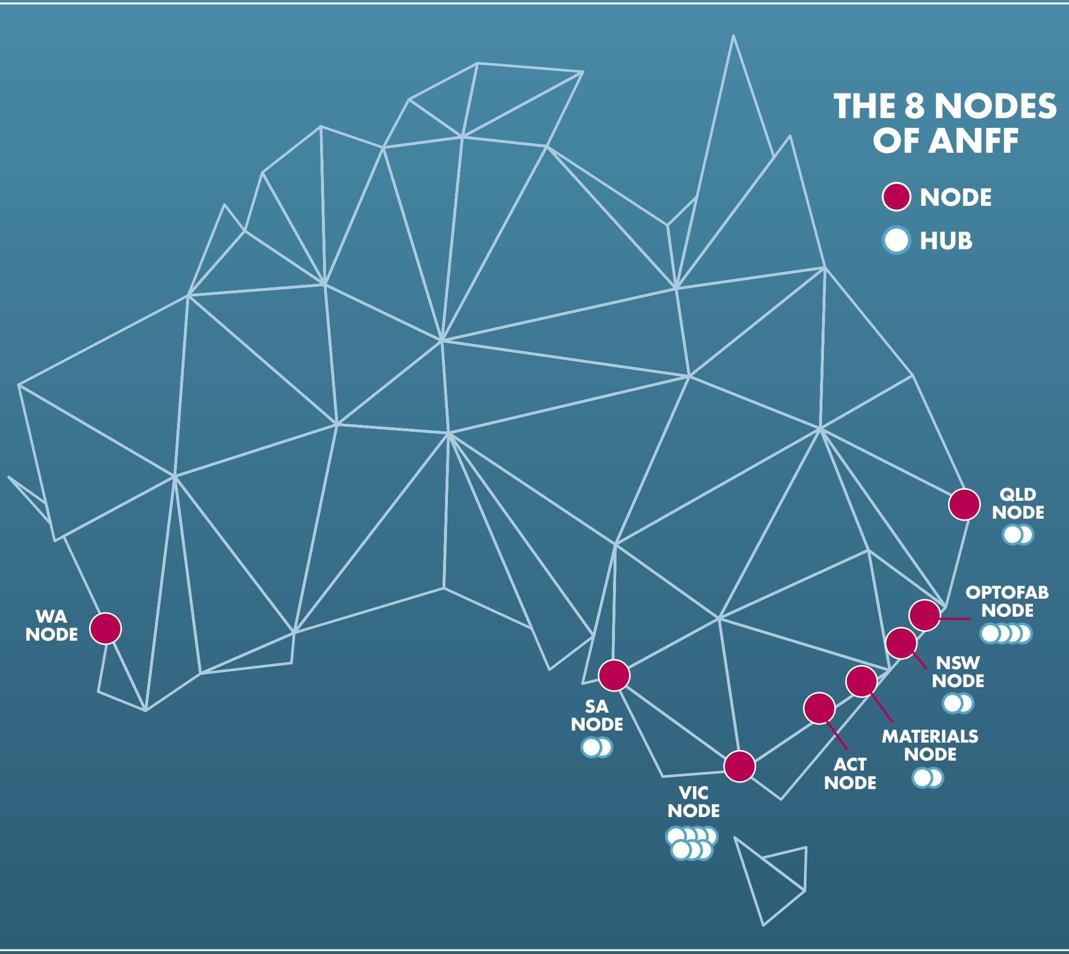
CONTENTS

SNAPSHOT OF ANFF

The Australian National Fabrication Facility (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.

More than 500 tools 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.



ANFF IN NUMBERS

Financial year 2021-2022 saw the ANFF network achieving the following fantastic outcomes despite COVID restrictions affecting normal operations.

21+yrs
185,321 hours of tool usage recorded

2,745
clients helped
– average time on tool per client was 67.5 hours

25,189
supplies manufactured

2,645
instances of process training, an increase of **8%** on the previous year

614*
publications that acknowledged ANFF in the calendar year 2020

60%
involving international researchers from 55+ countries

140
experts on hand to assist clients

* final published publications indexed with Scopus for the year 2021 that acknowledge using ANFF facilities

EMPOWERED BY ANFF

The pursuit of scientific advancement and technological innovation is becoming more sophisticated, increasingly complex and prohibitively expensive. Australia's National Research Infrastructure (NRI) maximises efficiency in the use of resources and services, minimises redundancy in equipment purchases, provides equality of access and facilitates multi-disciplinary research collaborations.

Every 5 years, the Australian Government publishes a NRI Roadmap that outlines Australia's current needs and future challenges in science research and development. Overall, the NRI Roadmap lays out strategies to maintain our global reputation for research excellence and to increase innovation, anticipate emerging challenges, strengthen our economic standing and build sovereign capabilities.

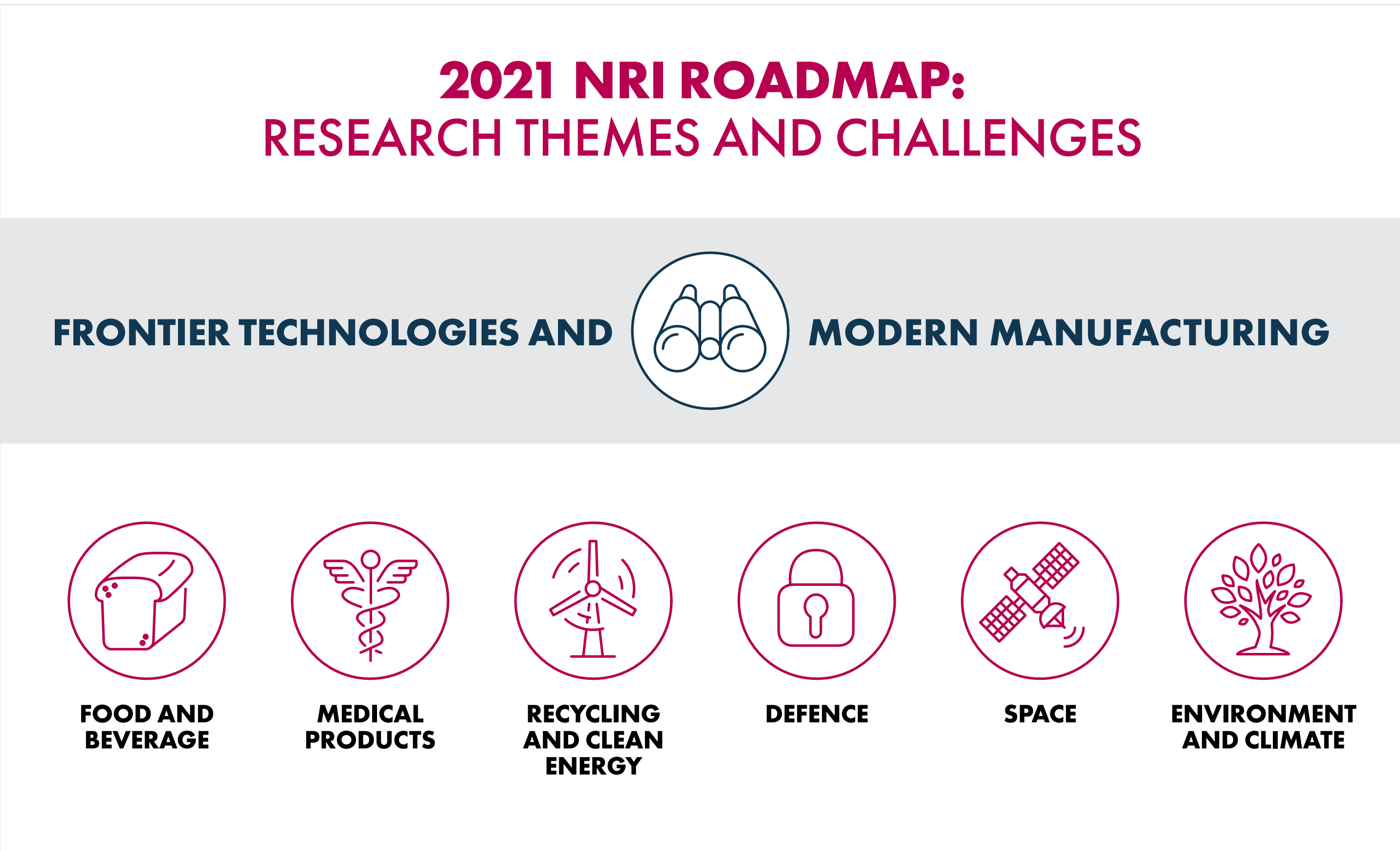
Since its inception in 2007 within the Department of Education's National Collaborative Research Infrastructure Strategy (NCRIS), the Australian National Fabrication Facility (ANFF) has empowered its clients to maximise their research, development, and commercialisation potential by providing access to micro- and nanofabrication-related facilities and expertise.

Frontier Technologies and Modern Manufacturing (FTMM) is one of the eight identified research challenge areas in the 2021 NRI Roadmap. The Australian government's Global Taskforce recognises nanotechnology and FTMM as critical enabling technologies for the other NRI Roadmap challenge areas shown in the graphic below.

As a key facility in the NCRIS system, ANFF is tasked not only with supporting research excellence in FTMM, but also to promote innovative, world-first technologies that solve real-world problems in diverse fields such as health care, communications, clean energy and climate change. Our users rely on ANFF for open access to Australia's world-class micro- and nanofabrication infrastructure.

ANFF is well positioned to meet the three key strategies laid out in the NRI Roadmap. First, the launch of ANFF-C will help increase the commercial impact of Australia's science research and technological innovations. Second, ANFF is taking the initiative to develop a highly skilled workforce in the science sector. We have partnered with TAFE-SA, South Australia's largest vocational education and training provider, to develop technician-style courses in micro- and nanofabrication. In addition, we are designing nanofabrication short courses to be delivered in our online learning, open-access platform, ANFF Enlightened. Third, our Client Engagement Team is smoothing the engagement pathway for our local industry.

The stories told in this 2022 Casebook provide a small sample of the amazing successes of our network's clients. We celebrate their accomplishments and highlight their impact in every sector of Australia's society. ANFF's expansive network of fabrication tools, facilities, and expertise is ready and waiting to empower your research and development now and in the future.



EASY OPEN ACCESS FOR ALL

ANFF's Client Engagement Team is opening the door to industry by making it easier for industry clients to engage with our equipment and expertise.

ANFF overcomes hurdles to science research and technological innovation by providing open access to Australia's world-class micro- and nanofabrication infrastructure, essential to this country's scientific and economic future.

In its 15-year history, ANFF has become an anchor for academic research and development, with coordinated facilities at 20 universities. However, as already highlighted in the 2021 National Research Infrastructure (NRI) Roadmap, industrial clients are not taking full advantage of ANFF's extensive infrastructure. With industry clients comprising only 10% of our client base, ANFF is devoting resources and personnel to better open its doors to this underserved sector.

The ANFF Network has improved its capacity to engage with industry by building a client-focused facilitator team, dedicated to spurring Australian innovation by simplifying the process of engaging with ANFF. Once the team obtains an extensive understanding of a client's research and their development and commercialisation plans, it provides the client with a roadmap describing how ANFF's expertise and infrastructure would be of assistance to them.

The Client Engagement Facilitators (CEFs), led by ANFF's Chief Strategic Partnerships Officer, are the primary contacts for any industry client whose needs transcend a single ANFF Node or for those that require assistance finding the best way that ANFF can support their project. CEFs provide concierge-level services, taking ownership of the client's problem and engaging the ANFF network to find the best possible solution.

The team's activities are central to the network's new organisational strategy which rolled out in late 2020 and strongly aligns with the NRI Roadmap. ANFF's more effective engagement with industry and other research end users will increase the impact of NRI investment and lead to greater translation of research.

The team has hit the ground running since coming on board, raising the organisation's profile at events, including the Sydney Quantum Academy, AusMedtech and ADSTAR Summit, and holding workshops for interested industry participants at relevant hubs. In addition, the participation of ANFF's Chief Strategic Partnerships Officer David Martin in national initiatives such as Australia's Semiconductor Sector Service Bureau (S3B) will more strongly connect ANFF to various industry sectors, both nationally and globally.

The focus areas of the CEFs align with the national priorities that ANFF is best positioned to support, namely, medical technologies, quantum and photonics, and space and defence.

With our strengthened focus on industry engagement, ANFF invites organisations from all sectors to get in touch with the CEF team to assess your requirements with access to tools and facilities or to provide support in addressing an advanced manufacturing challenge.

ANFF-C IS EMPOWERING BUSINESS

ANFF-C delivers out-of-lab support for commercially promising ANFF-enabled projects in collaboration with their stakeholders. Have a great idea? ANFF-C will help get it to market.

DR PIA WINBERG, DIRECTOR OF VENUS SHELL SYSTEMS.

ANFF technology platforms have supported great research outcomes that frequently have the potential to become commercial products. In many cases, this intellectual property has not been developed beyond the point of solving an interesting research problem.

Translating bench-top research into real-life products is time-consuming, costly, and often unsuccessful. Too many great ideas die in the translational 'Valley of Death'. While researchers excel at pushing the boundaries of what can be, they are not typically trained in the business of translation – overcoming the commercial hurdles of development such as identifying and understanding the target market and effectively communicating their business model to potential investors. Investing in proof-of-concept technology comes with great risk to seed grant agencies, angel investors and venture capital firms.

ANFF-C wants to see more of Australia's world-class basic research become successful commercial products and services. Our aim is to support early-stage ventures to reduce the commercial risk for potential professional investors. We do this by providing pre-seed capital that will assist new ventures in overcoming the hurdles of development, maximising the potential for successful outcomes. ANFF-C is now open for business and actively investing in great ideas.

ANFF-C has two investment stages. Gate 1 supports very early-stage projects that have demonstrated the feasibility of their product, with support up to $20,000. At this stage, ANFF-C funding is generally used for market validation ('who will pay for this?') and technical validation ('how can this be scaled?'). Gate 2 also supports early-stage projects with funding up to $100,000. To date, this money has been used for developing regulatory strategies and manufacturing plans, and it is also being asked to support studies to demonstrate the equivalency of the project's new technology with existing technologies.

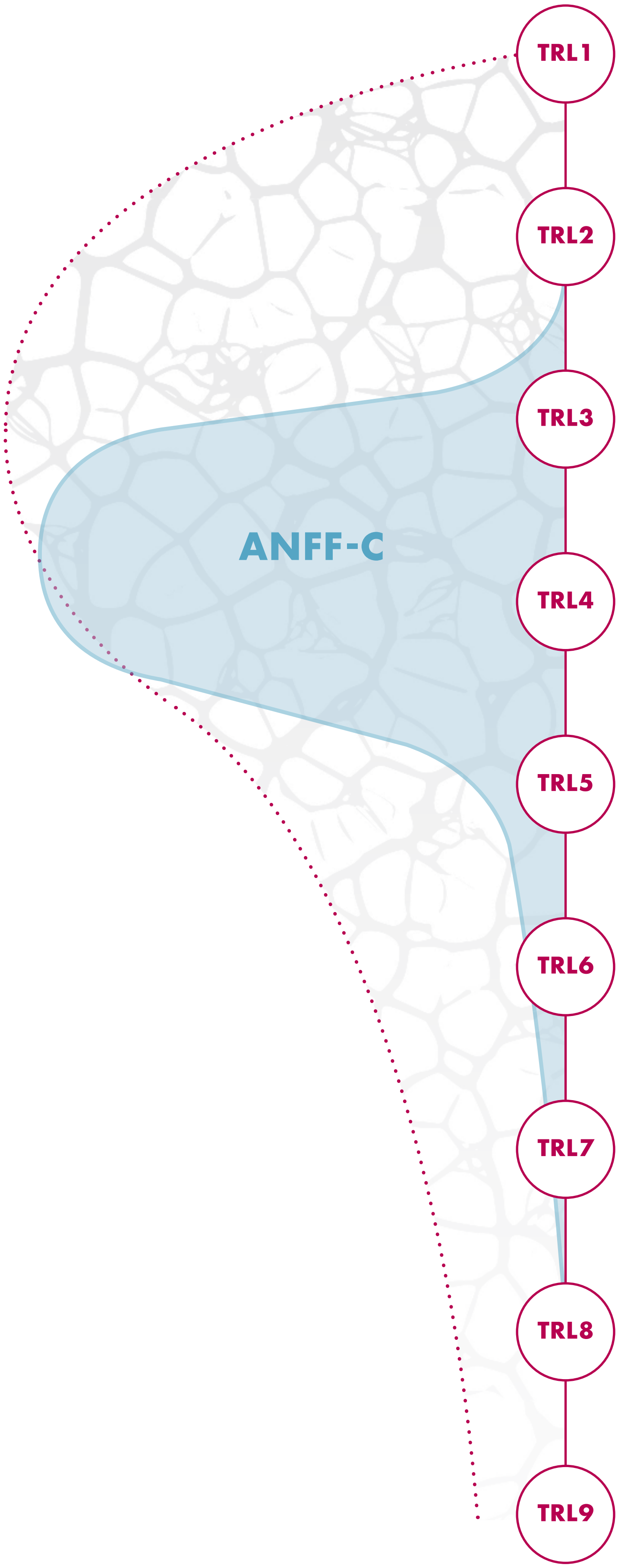
These two funding schemes can be pooled, but the total value that we can provide is $120,000. However, ANFF-C is open to leveraging its money with other university or commercial funding. For example, if a university has its own funding mechanism, ANFF-C would be open to sharing the costs of equivalency studies. We are looking to decrease the commercial risks associated with early-stage companies, making your venture more attractive to professional investors.

In many ways, our most valuable aid comes in the form of our networks and understanding of the sector-specific ecosystems. Our goal is to provide seamless integration of financial support and advice to early-stage entities to accelerate the start-up team's vision. More importantly, we attempt to highlight the commercial options available to early-stage entities. Hopefully this will attract the financing of professional investors or enable the entity to win support from some of the commercial funding schemes.

Moving forward, ANFF-C is looking for more opportunities to fill our pipeline. We want to know what is coming, even if a project is a couple of years away from being ready for financial support. This will enable us not only to plan better but also to potentially provide non-financial assistance. ANFF-C's broad range of capabilities on offer ensure that a client's exciting, innovative R&D can be supported as they look towards leaving the laboratory nest, headed for the stormy skies of industry. ANFF-C is open for your business to help your great ideas get to market.

PROCESS: **TECHNOLOGY READINESS LEVEL**

ANFF capabilities are useful at any stage on the pipeline, though focus may shift from device design and proof of concept, through to prototyping, and on to manufacturing process improvement and analysis/verification. To facilitate the commercialisation of new, innovative technology and companies, ANFF is now offering support through the ANFF-C platform to enable great technologies to become investment-ready enterprises, creating new companies and the jobs of the future.



TRL 1 – BASIC RESEARCH:
Initial scientific research has been conducted. Principles are qualitatively postulated and observed. Focus is on new discovery rather than applications.

TRL 2 – APPLIED RESEARCH:
Initial practical applications are identified. Potential of material or process to solve a problem, satisfy a need, or find an application is confirmed.

TRL 3 – CRITICAL FUNCTION OR PROOF OF CONCEPT ESTABLISHED:
Applied research advances and early-stage development begins. Studies and laboratory measurements validate analytical predictions of separate elements of the technology.

TRL 4 – LAB TESTING/VALIDATION OF ALPHA PROTOTYPE COMPONENT/PROCESS:
Design, development and lab testing of components/ processes. Results provide evidence that performance targets may be attainable based on projected or modelled systems.

TRL 5 – LABORATORY TESTING OF INTEGRATED/SEMI-INTEGRATED SYSTEM:
System Component and/or process validation is achieved in a relevant environment.

TRL 6 – PROTOTYPE SYSTEM VERIFIED:
System/process prototype demonstration in an operational environment (beta prototype system level).

TRL 7 – INTEGRATED PILOT SYSTEM DEMONSTRATED:
System/process prototype demonstration in an operational environment (integrated pilot system level).

TRL 8 – SYSTEM INCORPORATED IN COMMERCIAL DESIGN:
Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration).

TRL 9 – SYSTEM PROVEN AND READY FOR FULL COMMERCIAL DEPLOYMENT:
Actual system proven through successful operations in operating environment, and ready for full commercial deployment.

EUREKA PRIZES

The Australian Museum's Eureka Prizes are awarded to individuals and groups in recognition of excellence in science research and the understanding of science. The number of ANFF-enabled Eureka Prize Winners or Finalists stands as a testimony to the pervasive need for fabrication's many aspects of innovation. We celebrate the selection of our clients who have received recognition on this prestigious platform.

WINNERS

ANSTO Eureka Prize for Innovative Use of Technology (2022 Winner)

NANOMSLIDE

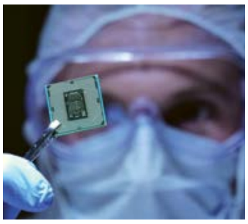
LaTrobe University researchers Dr Brian Abbey and Dr Eugeniu Balaur invented a sample slide coating that can passively increase contrast in standard microscopic images. The technology was extensively tested by Dr Belinda Parker at the Peter MacCallum Cancer Centre in Melbourne for its ability to make breast cancer cells easier to spot without the need for any dyes or extensive sample prep. You just put a bit of a biopsy on the slide, and the cancer cells 'pop out at you.' These researchers have created the new start-up company AlleSense to commercialise their NanoMslide technology.

ANSTO Eureka Prize for Innovative Use of Technology (2021 Winner)

INVENTIA LIFE SCIENCE

Prof. Justin Gooding, Prof. Maria Kavallaris AM, Dr Julio Ribeiro, Dr Aidan O'Mahony, Dr Robert Utama and Dr Lakmali Atapattu (UNSW; Australian Centre for NanoMedicine; Children's Cancer Institute; and Inventia Life Science Pty Ltd) have developed a technology to accelerate medical research by 3D printing accurate biological models on demand with their revolutionary RASTRUM 3D cell biology platform.

Defence Science and Technology Eureka Prize for Outstanding Science in Safeguarding Australia (2020 Winner)



EGGLETON RESEARCH GROUP AND A/PROF STEPHEN MADDEN

Prof. Benjamin Eggleton, Dr Eric Mägi, Dr Moritz Merklein, Dr Alvaro Casas Bedoya and Dr Yang Liu and A/Prof. Stephen Madden (University of Sydney and Australian National University) have harnessed the interaction of light and sound to produce a microchip that provides a unique advantage for defence platforms. With prototypes already developed in Australia and internationally, this compact technology launches a new era in microwave signal processing with real gains in performance, efficiency and cost.

FINALISTS

Eureka Prize for Excellence in Interdisciplinary Scientific Research (2022 Finalist)

NEW EARS

Silicone, or poly(dimethylsiloxane) (PDMS), is the most widely used facial prosthetic material due to its skin-like flexibility, heat resistance, biocompatibility, and intrinsic transparency. New Ears' 3D printer (3D Genii) is now capable of printing complex structures such as silicone ears and fingers with realistic shapes in different sizes by adopting modular design methodology. Their achievements provide a potential solution to the needs of prostheses manufacturers and many other areas of manufacturing such as fabrication of implantable structures from available TGA/FDA approved silicone materials.

Eureka Prize for Excellence in Interdisciplinary Scientific Research (2021 Finalist)

THE CARBON CYBERNETICS GROUP

Launched at the University of Melbourne by Prof. David Garrett and Prof. Steven Prawer, the Carbon Cybernetics group is striving to find a functional cure for epilepsy. Their world-first neural implant built from diamond and carbon nanomaterials can predict and stop seizures. Current materials engineering research focuses on optimising methods of integrating precious metal braze alloys with diamond and carbon fibres in the neural interfacing electrodes.

UNSW Eureka Prize for Scientific Research (2021 Finalist)

HO-BAILLE RESEARCH GROUP

Light-weight, cheap and ultra-thin, perovskite crystals have promised to revolutionise the photovoltaic cell market for some time. Prof. Anita Ho-Baillie, Dr Martin Bucknall and Dr Lei Shi (University of Sydney and UNSW) have produced a new generation of experimental solar energy cells that pass strict International Electrotechnical Commission testing standards for heat and humidity, increasing the commercial viability of perovskite solar cells.

UNSW Eureka Prize for Scientific Research (2020 Finalist)

AUSTRALIAN QUANTUM VORTEX TEAM

Led by Prof. Warwick Bowen and comprised of researchers from the University of Queensland, Monash University and Swinburne University of Technology, the Australian Quantum Vortex Team has been working to understand and harness interactions between waves in superfluid helium and light. Not only does their work lead to ingenious light-based technologies that require very little energy and are hypersensitive, but it also provides insight into turbulent systems such as cyclones.

ANFF is proud to have helped these projects and their innovators take their ideas and make them real. The team at ANFF will continue to develop our services to ensure that we have everything needed to support the next set of Eureka prize winners.

QUANTUM TECHNOLOGY

Quantum technology is a set of emerging technologies powered by the nature of subatomic particles to perform calculations instead of using electrical signals. While quantum technology holds much promise for faster computers, hack-proof data communications, increasingly accurate medical sensing, and so much more, there are significant hurdles to putting this technology to everyday use.

To precisely control, manipulate and measure the behaviour of subatomic particles, quantum systems must be operated at temperatures near absolute zero (-273°C). While quantum technology itself is small, the liquid helium cryogenic cooling chambers needed to supercool the systems can be room-size. When you add in other critical components like laser/optical systems and high vacuum chambers, quantum's price tag is out of reach for all but the largest companies such as Microsoft, IBM and Google.

The researchers and companies featured in this section are developing quantum technology that overcomes these hurdles – devices that operate at room temperatures, integrate with current computer technology and scale down to more compact sizes. ANFF clients are pushing the boundaries to bring quantum technology into your daily life.

MAKING QUANTUM TRULY SCALABLE

Diraq, the recently incorporated start-up company from the Dzurak Group at UNSW, are the global leaders in developing silicon metal-oxide-semiconductor (SiMOS) quantum-dot qubit devices for quantum computing.

In 1964, Richard Feynman, Nobel Laureate and the father of nanotechnology, said, ‘I think I can safely say that nobody really understands quantum mechanics.’ However, he later proposed harnessing it to build a more powerful kind of computer.

These computers are machines that use quantum phenomena to store data and perform computations. Quantum computers are predicted to solve many currently intractable problems, such as drug design and climate modelling. Long dismissed as science fiction, today we are in a race to build the hardware that will make quantum computers a reality.

Traditional transistors composed of silicon metal oxide semiconductors (SiMOS) control tiny currents of electrons. An applied gate voltage either allows current to flow from source to drain or not. Thus, a transistor acts as a binary switch in a circuit, existing in a charged or un-charged state. A charged state is considered a ‘0’, and an un-charged state a '1'. Computers have become faster, smaller and more efficient over time as transistors have become smaller, allowing more transistors on a computer chip. The processors in mobile phones and tablets contain billions of transistors on a single chip.

Innovative technology developed by the Dzurak Group Silicon Quantum Dot Qubit research program at UNSW has successfully created the world's first SiMOS-based quantum processor. Their quantum transistor controls a single electron – forming the fundamental unit of quantum information, the qubit.

By manipulating the surface gate voltage, a single electron is confined within a quantum dot. The spin of the electron, a property comparable to rotation, creates a small magnetic field. The binary nature of electron spin – clockwise (spin-up) or counterclockwise (spin-down) - makes spin an ideal candidate for the encoding of information.

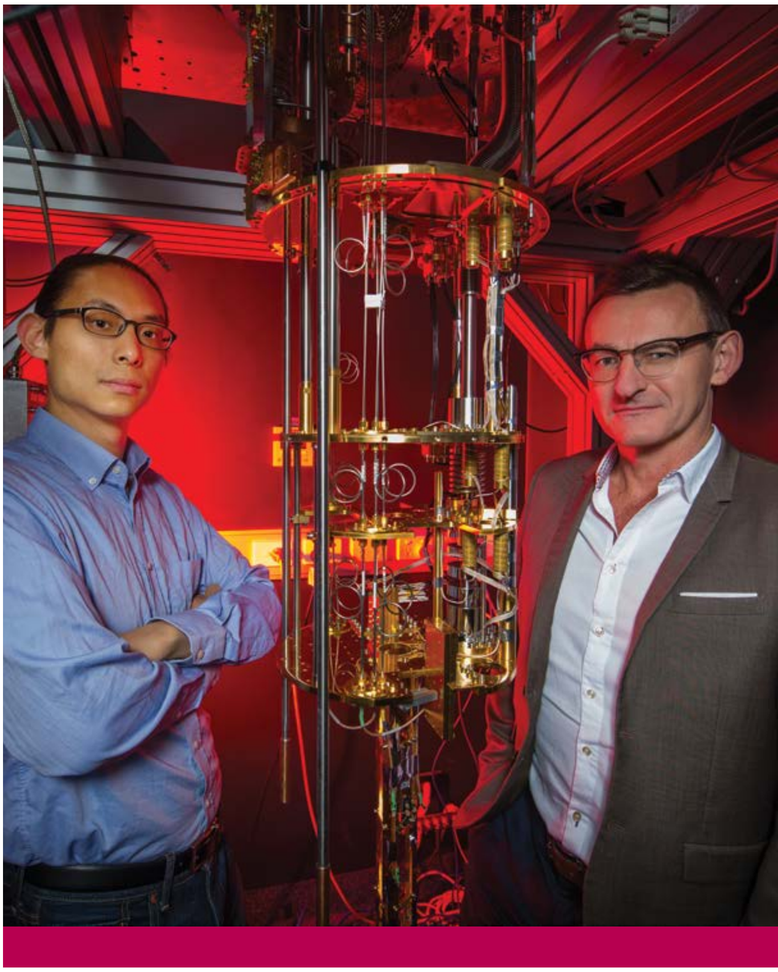
Within an applied magnetic field, the energy of the spin-up state becomes higher than spin-down. This energy difference enables read-write memory. We can verify the electron’s energy level, thus ‘reading’ the current state of spin (spin-down is 1; spin-up is 0) and can ‘write’ by flipping the electron’s spin state with a microwave signal of sufficient energy.

If you place two quantum bits side by side, microwave and voltage signals control the qubits and make them interact. In addition, the state of one qubit depends on the state of its neighbour. Letting these qubits interact creates logic gates capable of performing basic Boolean operations (AND, OR, NOT, etc.).

In the recent years, the Dzurak Group has achieved high fidelity single-qubit and two-qubit gates in silicon. More recently, they have explored the potential of ‘global’ spin qubit control in SiMOS quantum dot arrays to scale up the number of qubits to billions. Their revolutionary technology is compatible with the existing semiconductor manufacturing techniques – the only viable approach to scale up the number of qubits to billions for useful commercial applications.

The involvement of ANFF has been crucial to the creation of the first SiMOS quantum computing chip. The fabrication of silicon qubit devices is performed fully in-house in the ANFF-NSW cleanrooms. Without access to ANFF’s suite of state-of-the-art equipment and processes, the Dzurak Group's cutting-edge research and output rate would not be possible. In particular, the capability to grow high-quality silicon dioxide in high temperature furnaces plus access to nanometre-precision electron beam lithography has enabled them to construct world-class qubit devices.

This year, culminating from two decades of research, Prof. Andrew Dzurak has launched a start-up company – Diraq – which aims to redefine scalable quantum computing and bring practical commercial applications to the world via billions of qubits on a single chip.



PROFESSOR ANDREW DZURAK AND DR HENRY YANG WITH A MILLIKELVIN REFRIGERATOR, WHERE ANFF DEVICES ARE MEASURED.

USING CARBON TO SOLVE A QUANTUM DILEMMA

Archer Materials' ^{12}CQ carbon-based semiconductor chips will drive the development of a quantum computing processor that can operate in our daily lives.

Archer Materials Limited is an ASX-listed company developing the next generation of semiconductors for an increasingly mobile and data-centric world. Its innovative technology utilises carbon-based qubits rather than traditional silicon-based semiconductors for quantum computing. One key benefit of this approach is that it removes the need for the extremely low temperatures required by silicon-based quantum computing.

In 2019, the company inaugurated its flagship ^{12}CQ project focused on the development of a qubit created from 'nano-onion' carbon materials – spherical graphitic nanoparticles with an onion-like shell structure approximately 50nm in diameter. At their core, all quantum computers are comprised of quantum bits (qubits). Qubits are where the logic operations – program decisions based on multiple conditions (e.g. AND, OR, NOT) – are carried out. In Archer's case, the qubit states are defined by the spin state of electrons that are delocalised over the volume of these highly disordered carbon spheres.

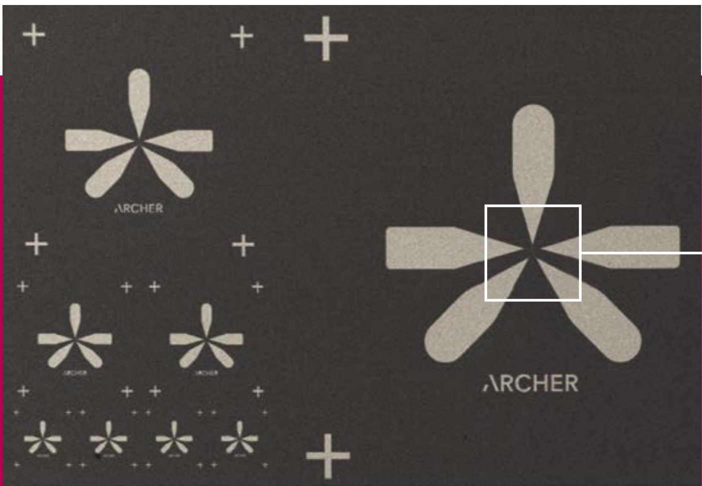
The quantum spin properties of nano-onion qubits create computer logic functions that are fundamentally different from the binary logic that defines the transistor hardware that we have used for the last 70 years. Quantum logic makes use of a peculiar quantum mechanical property called superposition in which a quantum object can simultaneously exist in more than one state. Superposition can be observed in the delocalised electron cloud of a nano-onion qubit, expanding the possible spin states of the delocalised electrons on the sphere: spin up (0), spin down (1), or spin that oscillates a little bit up and a little bit down at the same time (0 and 1). Quantum coding will facilitate a new type of computer hardware that can perform prohibitively difficult computational tasks very efficiently.

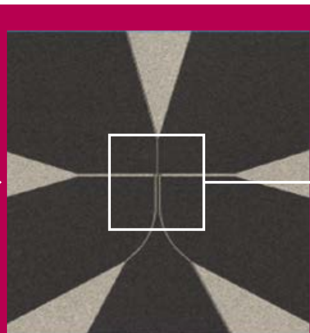
The aim of Archer's revolutionary ^{12}CQ chip technology is to develop this novel material into a viable qubit architecture that will allow for mobile quantum-enabled applications capable of operating at room temperature. Archer's current experimental activities are focused on developing a fully functional single qubit device.

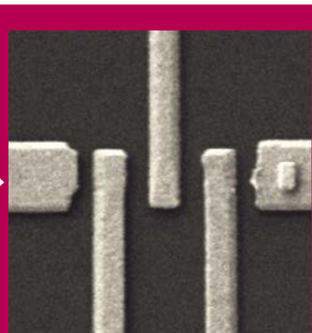
As a lab-less and fab-less semiconductor company, the company gains access to the required state-of-the-art infrastructure through collaboration agreements and facilities access agreements, most notably with ANFF. Archer's prototype development relies on ANFF-NSW cleanroom and nanofabrication facilities at UNSW and the University of Sydney's Research and Prototype Foundry. As Archer builds up in-house expertise with nanofabrication engineers, materials chemists and nanodevice physicists employed by the company, it also relies on the expertise of ANFF technical staff for certain tasks.

Innovative companies, such as Archer Materials, are playing an active role in establishing Australia as a world leader in quantum computing. Archer is translating the mind-bending concepts and theoretical potential of quantum mechanics into the hardware needed for quantum computing to become a reality. And Archer is going one step further by working towards hardware that operates at room temperature and easily integrates into existing modern electronic devices.

The computers that we use today were initially housed in huge rooms and used primarily by governments and large corporations like IBM. Similarly, the first quantum computers will run in the background of our lives, used by corporations to aid their efforts to develop more efficient drug discovery, ultra-secure internet and super-powered climate modelling. And just as we now all carry powerful computers in our pockets in the form of smartphones, Archer Materials' ultimate goal is to develop qubit-based architecture that will one day enable quantum-powered mobile devices to integrate into our daily lives.







A FABRICATED ARCHER ELECTRONIC NANODEVICE, WITH ITS FEATURES APPEARING AS THE LIGHTER SHADE.

A DIAMOND MICRO-OPTIC HALF-SPHERE.

DIAMONDS ARE QUANTUM'S NEW BEST FRIEND

The Australian/German company Quantum Brilliance is developing powerful quantum accelerators that will integrate into today's computer systems, creating faster, more powerful hybrid technology to meet the computing challenges of tomorrow.

Rather than trying to replace supercomputers, Quantum Brilliance's goal is to make quantum computing an everyday technology, with hardware that works in coordination with our current technology to overcome the limitations of our classical computers. Quantum Brilliance's quantum accelerators are based on diamond and work at room temperature, undercutting and outperforming today's huge, cryo-cooled, quantum supercomputers. Their quantum accelerators currently fit in a standard 19-inch server rack, and soon they'll be small enough for mobile devices.

Key to their diamond quantum computer are defects called vacancies created in the diamond, points in the lattice where a carbon atom is missing. By substituting nitrogen atoms into the lattice next to these vacancies, nitrogen-vacancy (NV) centres are created within the diamond's structure.

Each processor node is comprised of a single NV centre and a surrounding cluster of atoms: the nitrogen itself and up to 4 nearby carbons. Within that cluster, the nucleus of each atom spins (rotates), and the nuclear spins of ^{14}N and ^{13}C atoms act as qubits. The electronic spin of the NV centre acts as a quantum bus, controlling the initialisation and readout of the qubits surrounding the NV and connecting their behaviour to other parts of the computer's architecture.

Quantum computation is controlled via external energy inputs such as radiofrequency, microwave, optical and magnetic fields. Absorbance of green light elevates the nuclear spin to an excited, higher-energy state. Relaxation of that spin back to a more stable, lower-energy state leads to the emission of red light, a phenomenon called fluorescence. This fluorescence signal provides an optical readout, or visual data record, from the qubit.

A critical parameter for NV centre initialisation and readout fidelity is the detection rate of fluorescence photons released from the NV. Diamond has a much higher refractive index than the surrounding air, so emitted photons become trapped within the diamond lattice and can't escape easily. Total internal reflection at flat diamond-air interfaces confines and traps most of the NV fluorescence inside the diamond.

One promising path toward fixing this problem is to texture the diamond with micro-scale patterns to improve the light extraction efficiency. Dr Vivek Raj Shrestha, an optics and nanofabrication engineer at Quantum Brilliance, has created micro-optic structures on diamond including microscopic half-spheres and parabolic mirrors to enhance the extraction efficiency of light from the NV centres. Increasing the light extraction efficiency increases the fraction of emitted power that escapes to the air (or into a desired solid angle), providing higher-fidelity readout from qubits.

Dr Shrestha harnessed the focused ion milling capabilities at Melbourne Centre for Nanofabrication (MCN) and ANFF-ACT to develop a manufacturing process for creating such microscopic structures in diamond at the precise locations of NV centres pre-determined using Quantum Brilliance's home-built confocal microscopy set-up.

Quantum Brilliance's ability to manufacture miniaturised diamond qubits in a precise and replicable process and to optimise the control structures for qubit initiation and readout are propelling this company to the forefront of quantum computing hardware design. Integration of quantum accelerators with existing architecture will bring the benefits of quantum computing more quickly into industries that impact our daily lives like pharmacological drug development, battery electrode development and energy generation, machine learning, and AI.

SPACE AND DEFENCE

Research and development in the space industry have led to inventions that improve human societies and protect the environment. Memory foam, advanced water filtration, invisible braces, scratch-resistant glasses, CAT scans, and LASIK are among the many space products that have become commonplace in our daily lives. Space technologies enable activity across Australia's economy. The country's emerging global position in the space sector is underpinned by research expertise, geographical location, cutting-edge facilities and advanced manufacturing capabilities.

In a complex global system, Australia must maintain its defences against external threats. Innovative development of defence materials, components and equipment underpins national security. Emerging defence technologies can have an impact both in the military ranks and in all areas of our society.

The NRI highlights the challenge of increasing Australia's international competitiveness and success of its space and defence industries. By empowering the work of inventive researchers and start-up enterprises, ANFF supports the development of products that have a real-life impact both locally and internationally and bolsters sovereign production capacity.

PROTECTING THE WORLD FROM HOMEMADE EXPLOSIVES

Researchers from Victoria University have developed an innovative new approach for rapid screening of peroxide-based 'homemade' improvised explosive devices (IEDs).

IEDs sow the seeds of death and destruction, and the terrorists and criminals that create them seek to spread fear, destabilise governments and divide society.

IEDs based on explosives such as nitroglycerin, TNT, military Semtex and C4, and fertiliser-derived nitrates are relatively difficult to make at home. The starting ingredients are hard to obtain, and the chemical synthesis isn't easy to perform. A certain level of training or expertise is needed to work with these materials. However, a new generation of explosives – organic peroxide explosives (OPEs) – have placed the potential for massive destruction into the hands of those with ill intent who previously did not have the access to the materials or chemical expertise needed to create IEDs.

Peroxides are chemicals that contain a peroxy functional group in which two oxygen atoms are linked together by a single covalent bond (-O-O-). Peroxides are good bleaching agents, have wonderful antiseptic and disinfectant properties and are excellent solvents. In fact, you probably have peroxide products in your home in the form of hair dyes, hydrogen peroxide, nail polish remover, cosmetics and toothpaste.

What makes OPEs so dangerous? OPEs contain very unstable peroxy groups that are highly reactive. Easily exploding with heat or friction, their destructive power rivals that of military grade materials. It is surprisingly easy to make a 'homemade' OPE bomb. Starting materials can be easily purchased in large amounts in convenience and grocery stores because the ingredients are used in our everyday lives. A person doesn't need to be a chemist or have specialised training to convert these innocent products into explosive devices.

Several global incidents demonstrate the increasing use of OPE-based IEDs to terrorise people going about their daily lives: football stadiums and theatres (Paris 2015), airports (Brussels 2016), concert venues (Manchester 2017), and churches and hotels (Sri Lanka in 2019 and Indonesia in 2018 and 2021)). While not exhaustive, this list illustrates the invasion of IEDs into the places where we work, relax and worship.

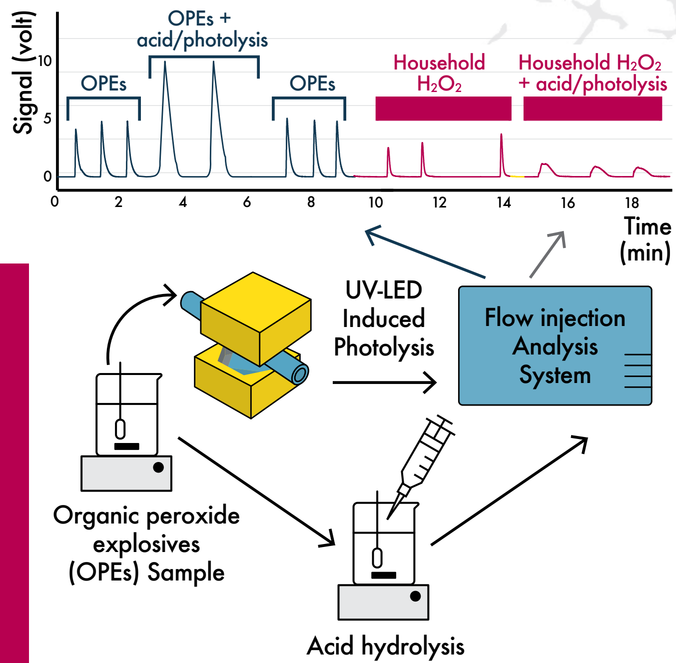
Current screening technologies identify trace amounts of commonly used explosives in the air. However, these devices fail to distinguish OPEs (real positives) from other peroxides (false positives). Unfortunately, fast screening of OPE-based IEDs presents a real challenge for airport and venue security, first responders and military personnel.

Our inability to rapidly and clearly discern harmless from harmful peroxides demands an alternative rapid screening system. The detection device must be portable, fast, and easily used by both soldiers or civilians at airports, transportation hubs, and high-profile events like concerts and sporting occasions.

Dr Chowdhury Kamrul Hasan and Dr Parvez Mahbub of Victoria University's Institute for Sustainable Industries & Liveable Cities have developed a microfluidic system employing acid hydrolysis or photolysis to 'break' down peroxides. OPE degradation pathways differ from that of commonplace hydrogen peroxide. Initial testing shows that their screening system can detect these differences and clearly differentiate OPEs from hydrogen peroxide. With the ability to analyse swabs within 12 seconds, their system provides the critical speed needed in real-life screening situations.

However, it is not enough to demonstrate that the chemistry works. Researchers must prove how it works before their new detection method can be adopted and replace older technology. Drs Hasan and Mahbub teamed up with ANFF-Vic and the Melbourne Centre for Nanofabrication (MCN) to uncover the chemical mechanism for how the system reactions proceed (e.g. identification of chemical intermediates).

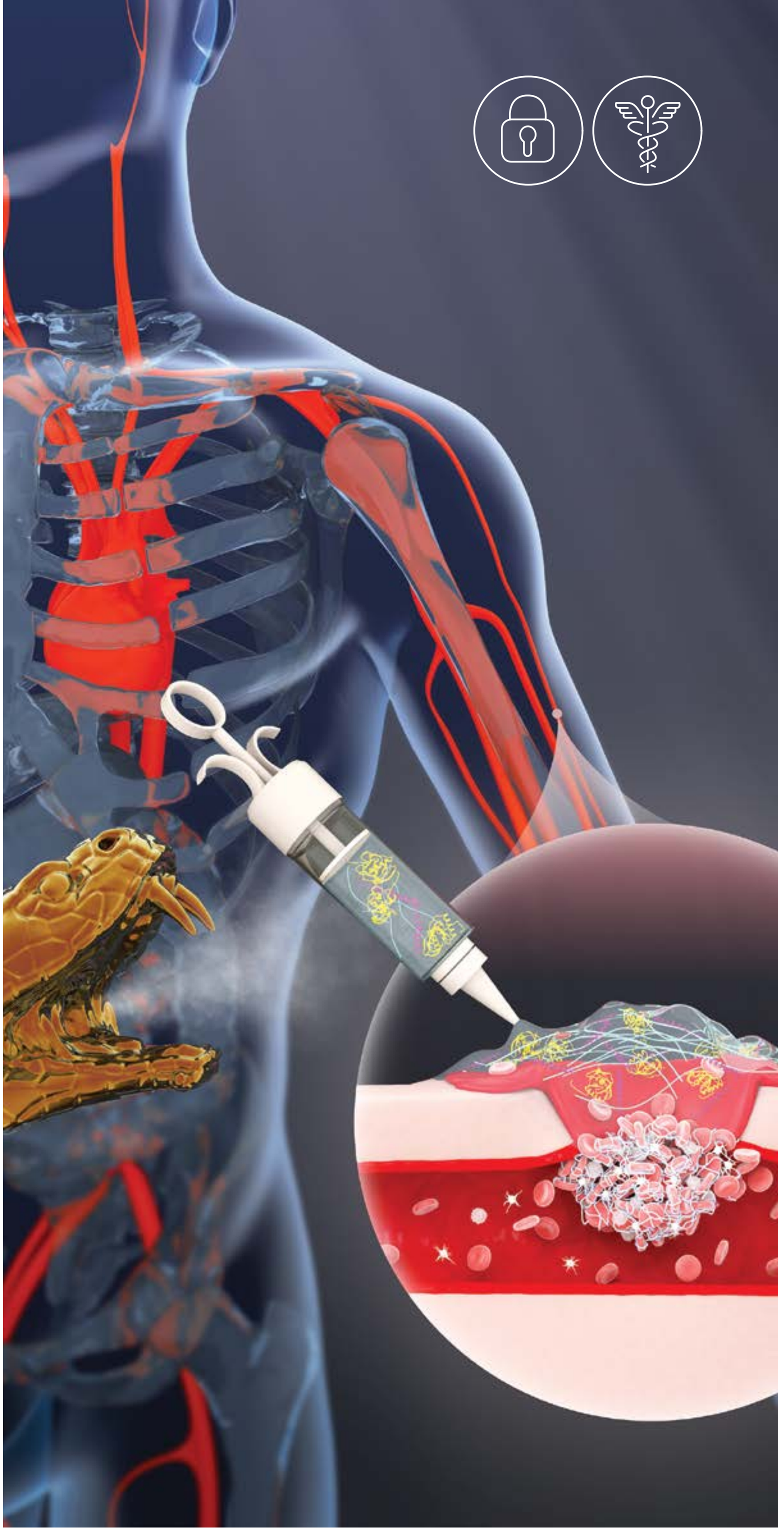
With the chemistry firmly established, future work will focus on fabricating a microfluidic prototype and performing a comparative study against the conventional screening system. Hasan and Mahbub, in collaboration with ANFF and the Defence Science and Technology Group (DSTG), plan to demonstrate the effectiveness of their prototype device in actual field conditions with human volunteers, hopefully leading eventually to a way to further protect our day-to-day lives.



SCHEMATIC OF A MICROFLUIDIC RAPID SCREENING SYSTEM FOR PEROXIDE DETECTION.

DR SNAKE TO THE EMERGENCY ROOM

A person can bleed to death in minutes. University of Queensland researchers are taking inspiration from nature to develop unique hydrogels that can save people from blood loss incurred during traumatic injury.



Bleeding out from traumatic injury is a leading cause of preventable death worldwide, second only to brain and spinal cord injuries. In fact, 30-40% of civilian deaths and 90% of military mortalities are due to uncontrolled bleeding. More than half of these deaths occur before an injured person can even reach the hospital.

A first-aid kit offers little actual aid to a person in an emergency bleeding situation – place gauze on the wound and apply pressure. If the blood loss is from an arm or leg, the manual tells you to look around your surroundings and hope you find materials suitable for a tourniquet.

Easy-to-pack and easy-to-use wound treatment products are needed that effectively stop uncontrolled bleeding. Being able to treat soldiers and civilians at the point of injury has tremendous potential to save lives and reduce the mortality from traumatic injury.

Based at the Australian Institute for Bioengineering and Nanotechnology (AIBN), postdoctoral research fellow Dr Amanda Kijas and Prof. Alan Rowan have taken their cues from nature to develop novel wound management agents.

Which animal species are master manipulators of the human circulatory system? You need look no further than venomous snakes. While some compounds in venom destroy capillary vessels and cause internal bleeding, others activate the blood clotting system and block blood vessels, which can induce a stroke or heart attack.

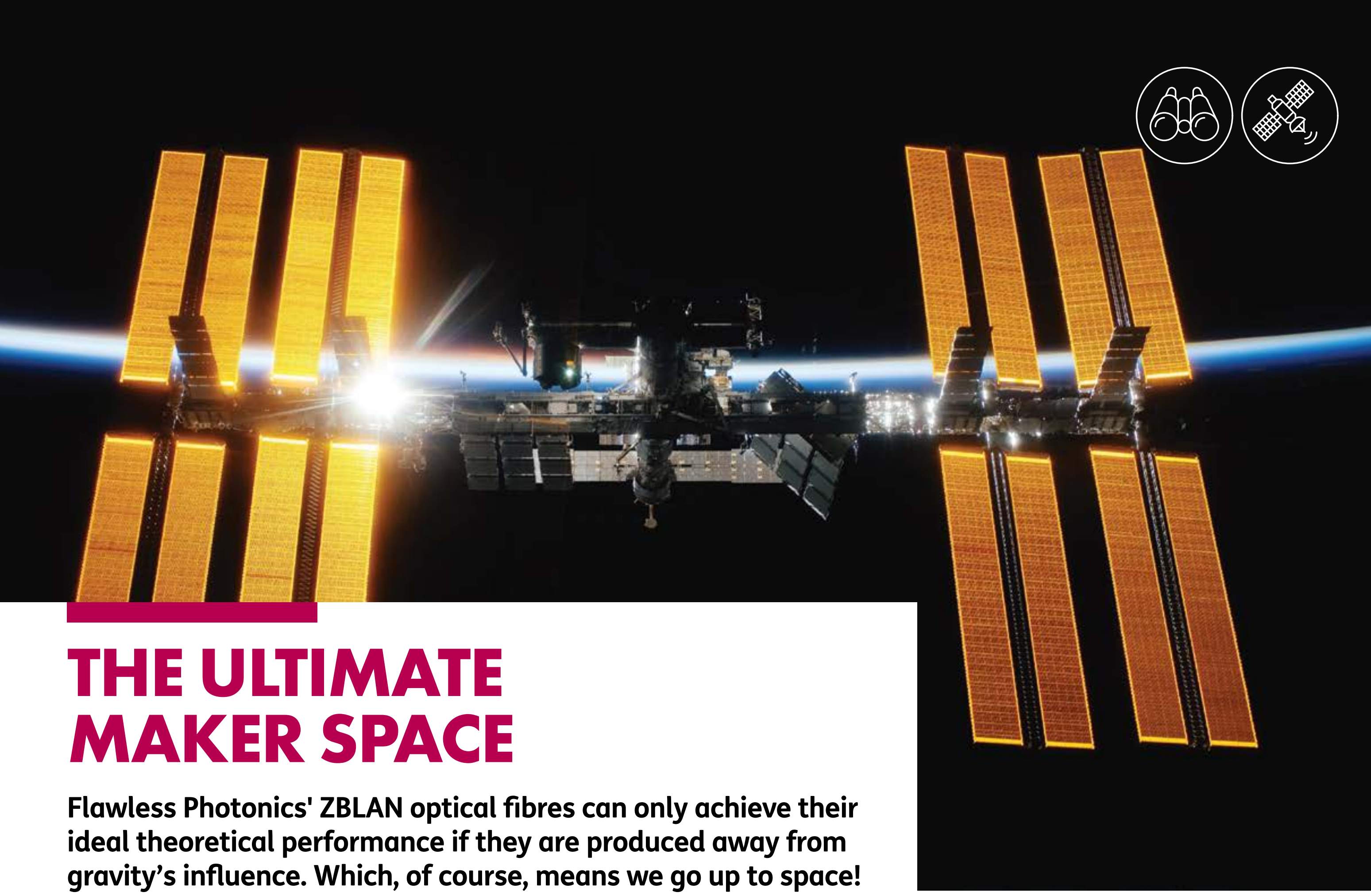
With support from ANFF-Q facilities hosted at AIBN, the team has developed a revolutionary wound treatment system that uses potent proteins derived from venomous snakes to both accelerate clotting and retain a stable blood clot. One such snake venom protein, ecarin, begins a series of biochemical reactions that leads to the formation of fibrin, long fibres that interact with platelets to form a clot over a wound site. Overall, ecarin supercharges the clotting process and stems the flow of blood.

However, triggering clot formation within a wound is limited in effectiveness if the blood clot subsequently breaks down, a process called fibrinolysis. A major shortfall of many currently employed haemostatic (or clotting) agents is the lack of an anti-fibrinolytic agent to counter blood clot breakdown. The novel system described in this work employs a second snake venom protein called textilinin that effectively counters fibrinolysis. The addition of textilinin adds a unique capability not seen in other point-of-injury wound treatment products.

Fortunately, these venom proteins can be easily produced in the laboratory, which is much easier on both the snakes and the snake milkers. Yet, these haemostatic proteins form only part of the picture, as they need to be effectively delivered to the site of injury to have any effect. In the product, the proteins are delivered within a topically applied, thermo-responsive hydrogel to seal the wound. Below room temperature, the polymer material takes the form of a liquid. When applied to a wound, body heat warms the material, and the polymer transitions into a stable matrix similar to a jelly.

Proof-of-concept in vivo studies have demonstrated the overwhelming effectiveness of their wound treatment system, achieving a striking 5-fold reduction in blood loss and a 3-fold reduction in clotting time. In addition, this unique haemostatic hydrogel can form rapid and stable blood clots even in the presence of blood thinners.

With such promising initial results, this revolutionary product has been awarded funding from the US Department of Defense, to undertake preclinical evaluations to gather more data on the safety and efficacy of this agent. The team can envisage a near future in which their wound management hydrogel will become a standard component in first aid kits and soldiers' packs, enabling bystanders or the wounded themselves to rapidly stop bleeding, improving patient outcomes and, in the end, saving more lives.



THE ULTIMATE MAKER SPACE

Flawless Photonics' ZBLAN optical fibres can only achieve their ideal theoretical performance if they are produced away from gravity's influence. Which, of course, means we go up to space!

Optical fibres use light pulses to transmit information along optic cables rather than the electrical pulses employed in copper wire transmission. The use of optical fibre in telecommunications and data communications is rising due to optical fibre's unbeatable advantages over copper wire such as faster speeds with less signal degradation and greater information carrying capacity. Yet, as data demands grow and our need for broader spectrum bandwidth continuously increases, even the capabilities of conventional silica glass optical fibres are being stretched to their limits.

As a result, there is growing interest in developing extremely low-loss, wider spectrum fibres for data and telecommunications. Flawless Photonics is a California-headquartered company focused on making fluoride-based fibres that incorporate zirconium, barium, lanthanum, aluminium, and sodium (ZBLAN). The theoretical capabilities of special ZBLAN glass far exceed those of silica glass by many times over.

So, what's the catch? Real-world performance of fluoride fibres does not live up to expectations due to chemistry issues that occur when the fibre is produced under the influence of gravity. ZBLAN optical fibres can only achieve their ideal theoretical performance if they are produced outside of gravity. There is literally nowhere on Earth where these fibres can be optimally fabricated. Which of course means we look to space for the solution!

Flawless Photonics is pioneering the manufacturing and supply chain of next-generation optical fibres from space known as SpaceFiber™. Flawless is the first entity to successfully manufacture optical fibres in microgravity, aboard the International Space Station (ISS). In April 2019, their prototype space manufacturing platform was delivered to the ISS by the Northrop Grumman robotic resupply spacecraft Cygnus. The platform itself was self-contained and only needed to be plugged in by the crew, after which Flawless Photonics operated the device remotely. Once fabricated, SpaceFiber™ was delivered back to Earth so that the ZBLAN glass fibre can be used terrestrially.

Through a partnership with University of Adelaide's Prof. Heike Ebendorff-Heidepriem and the ANFF- Optofab Adelaide hub, Flawless Photonics is optimising the glass purification processes, preforming and fibre drawing processes. ANFF-Optofab provides consultancy on ZBLAN glass fabrication, fabrication of ZBLAN samples for testing by Flawless and investigation of methods for raw material purification. ANFF's Adelaide hub has the capability for ZBLAN glass melting, casting, extrusion and fibre drawing, and now are in the process of building the capability for ZBLAN raw material purification. Together, Flawless Photonics and Adelaide Optofab are working on the next generation of the space manufacturing platform in order to scale up SpaceFiber™ production on the International Space Station.

SpaceFiber™ will revolutionise several industries that currently use optical fibres by enabling entirely new products and applications that simply can't exist because of silica fibre's limits and from gravity's effects on special glass like ZBLAN. From high power fibre lasers in the mid-infrared spectrum, to exceptionally sensitive sensors at MIR wavelengths, to hyper-low-attenuation fibre optic data connections that extend thousands of kilometres without the need for amplification, the sky is literally no longer the limit.

HEALTH AND LIFE SCIENCES

Innovation in health and life sciences is bookended by two types of 'white coats': laboratory researchers at the benchtop pushing the boundaries of knowledge and medical doctors/clinicians at the patient's bedside providing life-saving treatments. In between is the field of translational science (benchtop-to-bedside) that converts biomedical research discoveries into real-world diagnostic platforms and medical devices and treatments that improve patient outcomes.

Unfortunately, most bespoke benchtop discoveries meet their demise in the translational ‘Valley of Death’ in which problems with reproducibility, scalability, safety and cost create insurmountable obstacles to product development. ANFF's micro- and nanofabrication infrastructure, along with ANFF-C's commercialisation expertise, is bridging the translational gap for medical researchers and early-stage companies. We empower our clients to successfully develop their innovative discoveries into real-world products that impact society.

The stories in the Health and Life Science section describe chasm-leaping medical devices with the potential to change current standard of care and increase positive outcomes for everyone in our societies, from infant to elder.

MICRO PLUMBING TO HELP MORE PEOPLE BECOME PARENTS

Poised to increase in vitro fertilisation (IVF) treatment success rates, a team of pioneering Australian researchers have developed an automated microfluidic platform to standardise complex IVF processes.

In Australia alone, one in six couples is affected by infertility problems. In vitro fertilisation (IVF) is the most effective assisted reproductive technology, used to help couples with fertility issues and assist with conception. After embryologists or medical laboratory scientists fertilise eggs with sperm in a laboratory petri dish, the fertilised egg is grown in culture for 2-6 days before being transferred into the uterus. IVF is a long and expensive process with a low overall success rate of only 18%. With only one in five harvesting cycles resulting in success, IVF requires multiple attempts, financial security, emotional toughness and years-long patience.

Although IVF is a long-established treatment, the techniques used in the procedure have changed little since the first successful IVF birth in 1978. Couples should be afforded equal opportunity for treatment; however, success rates depend heavily on clinic selection. While IVF clinical and laboratory procedures are standardised, there is wide disparity in success between different fertility clinics. Operator handling of the embryos during fertilisation and throughout the subsequent culturing process can be damaging to the embryos. Even slight variability in how laboratory procedures are performed and how embryologists handle these precious cultures greatly influences the final outcomes.

Adelaide University PhD candidate Suliman (Suli) Yagoub, a member of the Centre for Nanoscale BioPhotonics' Reproductive Success team, worked in partnership with researchers from RMIT University and with support from ANFF-SA to design and fabricate a novel embryo housing device for use by embryologists. Mr Yagoub and his colleagues aimed to increase the overall success rate of IVF and to reduce the disparity among clinics by removing the variability resulting from human handling of the embryos.

Their platform supports a standardised, yet dynamic system, enabling embryologists to culture embryos to the desired stage of development using a computer-monitored microfluidic pump to control the microenvironment. Operators handle embryos only when initially placing fertilised eggs into the device and removing developed embryos when ready for implantation. Growth media is continuously delivered to the embryos, with culture conditions monitored by computer, removing possible operator variability or error in embryo handling and culture maintenance. The device can be modified to house a variable number of embryos, with the ability to control the microenvironment for each embryo. In addition, the device itself can be cryogenically stored, allowing cryopreservation of eggs or embryos without the need for any additional handling.

Using an individualised, customised platform for each client requires the ability to develop high-throughput printing and fabrication methods for these micro devices. In July 2019, Suli attended ANFF-SA's Microengineering Winter School where he participated in lectures and practicals to enhance his understanding of micro- and nanofabrication before undertaking training in microfabrication with the ANFF-SA team.

Combining reproductive biology, physics, chemistry and engineering, Suli's multidisciplinary research requires him to think outside the box. ANFF-SA has supported his research with one-on-one training with highly skilled staff and access to the cleanroom to fabricate his own prototype microfluidic devices. He credits his improved skills in microfluidics, fabrication and 3-D modelling to ANFF-SA's staff who 'have supported me with my designs, provided insightful advice that allowed my research to progress faster than anticipated and made sure I have access to all the resources available for me to get the best results.'

Suli Yagoub's research in the Reproductive Success team will benefit IVF centres around the world by increasing the success rate of IVF and reducing the psychological and financial costs on would-be parents, who are increasingly relying on IVF to start a family.

DR SULIMAN (SULI) YAGOUB AND HIS REVOLUTIONARY MICROFLUIDIC EMBRYO HOUSING DEVICE.

SHINING A LIGHT ON BRAIN FUNCTION

Optical-electrode (optrode) technology has emerged as a promising tool that can probe complex electrical signals from cells and tissues.

Neuroscience research has progressed rapidly in the recent past, targeting the treatment and management of many mental conditions and diseases. To study brain physiology, scientists conduct electroencephalogram (EEG) tests in which neural electrical activity is monitored by placing electrodes onto the scalp or into tissues. EEG can be used to determine the overall electrical activity of different brain regions and to diagnose disorders that influence brain activity. However, EEG suffers from limited spatial resolution, providing a rather crude overall picture of brain function.

To gain a more sophisticated understanding of neural activity, researchers need to go deeper into the brain and reduce the size of the electrodes to measure activity at the level of a single neuron. Current technology is insufficient to meet these demands.

Researchers in Scientia Prof. Nigel Lovell's laboratory at the UNSW Graduate School of Biomedical Engineering and Prof. François Ladouceur's group at the School of Electrical Engineering and Telecommunications have developed a new probing and monitoring technology based on passively generating optical signals from cellular electrical activity.

PhD candidate Reem Almasri and ANFF-NSW Process Engineer Josiah Firth have fabricated optical electrodes (optrodes) based on a liquid-crystal sensor that can measure bio-electrical signals. Their optrodes passively convert these signals into measurable optical output without using the traditional molecular biology approach of attaching fluorescent tags to biomolecules or cellular structures to convert electrical impulses into an optical output.

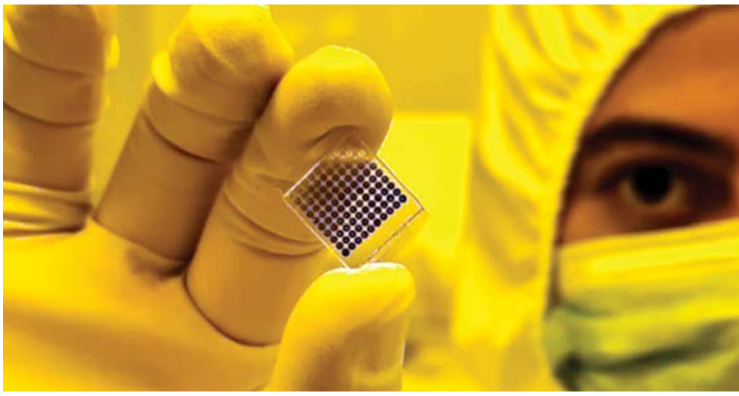
The optrode combines a conductive interface that can detect a biological electrical potential and an underlying layer of liquid crystals that can convert the stimulus into an optical signal. Liquid crystals, not unlike those found in LCD monitors, are very sensitive to electric fields. When a neuron fires, triggering an action potential that changes the electrical field across the cell membrane, there is a corresponding change in the orientation of molecules within the liquid crystal.

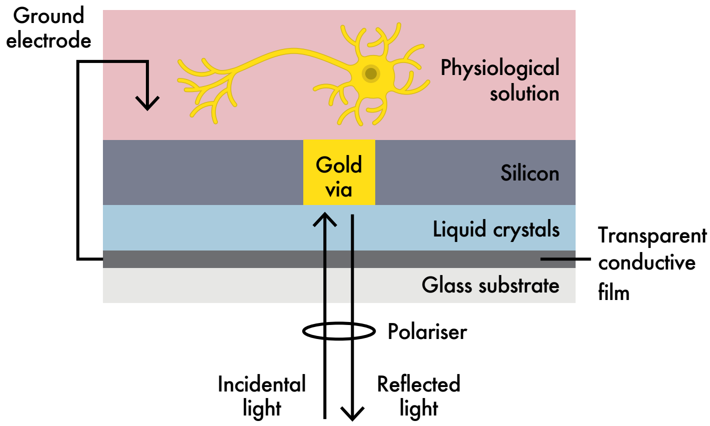
An optrode uses an optical fibre to shine light on the liquid crystal sensor and to measure the light reflected from a mirror embedded within the sensor. Neural impulses will induce a measurable change in that reflectance, thus passively transducing the electrical event to an optical signal.

Direct contact of the optrode with soft biological tissues adds some specific requirements on the device properties to achieve a robust, flexible interface. This includes re-engineering biocompatible materials and flexible architectures to transform the rigid industrial version of this sensor into a clinically viable design.

Ms Almasri's work consists of investigating potential candidate materials and architectures that are compatible with and suitable for the optrode's design and functionality. In work performed at ANFF-NSW, this re-engineering was achieved by depositing, patterning, and characterising conductive and dielectric flexible materials to mimic the tissue properties and withstand the surrounding biological environment.

This research group's optrode technology provides a scalable solution that can be employed at the cellular level. They have successfully employed optrodes to record peripheral nerve responses in animal models. This work has expanded beyond neurons to other electrically active cells in the body such as cardiomyocytes, cells in the heart that also produce action potentials. They have successfully used the optrode sensor to record the heart's electrical signals in animal models.





PHD CANDIDATE REEM ALMASRI HOLDING A MULTI-OPTRODE ARRAY, AND A SCHEMATIC OF THE LOVELL GROUP'S OPTRODE DEVICE

Dr Saeb Mousavi, a research engineer within the Lovell group, is exploring an alternative optrode fabrication technique that involves direct 3D printing of conductive and insulating inks to achieve flexible optrode devices. This technique is particularly useful as it is simpler and has a lower cost compared to the complicated and expensive cleanroom microfabrication techniques.

Almost one in six people worldwide have a neurological disorder such as dementia, Parkinson's disease and epilepsy, with cases expected to rise as our populations age. Since these disorders are currently incurable, early diagnosis and monitoring are critical in providing appropriate care that maintains a patient's quality of life. Given the promise of this innovative optrode technology to provide close monitoring of brain activity, future doctors will have a powerful tool to localise and/or track these neurological disorders, contributing to better patient outcomes.

CREATING SAFER SURFACES FOR LIFE SAVING MEDICAL IMPLANTS

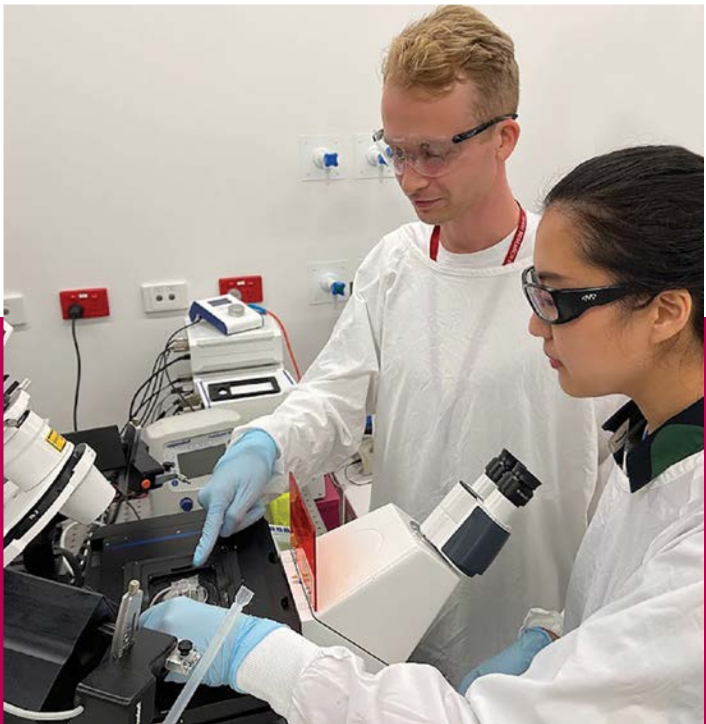
Dr Anna Waterhouse and her dynamic research team from the University of Sydney (USYD) are developing next generation surface coatings that reduce the risk of blood clots forming on the implantable medical devices used to treat cardiovascular disease.

For people living with heart and blood vessel disorders, implanted medical devices including stents, vascular grafts and ventricular assist devices can improve or extend their lives. An implant's biocompatibility is determined by the blood-material interface and blood flow conditions.

Of high concern for the long-term success of a medical implant is the risk of thrombosis, the formation of blood clots. Clotting factors that circulate through the circulatory system can adsorb onto implant surfaces, initiating the conversion of fibrinogen precursors into long fibrin strands. These strands act as a net that traps circulating cells and platelets, forming a blood clot. Blood clots can lead to blocked arteries and other complications that result in device failure. In addition, the clots can break off, especially under high blood flow conditions, causing other life-threatening complications like strokes. Blood thinning treatments can help prevent clots but increase bleeding risk in patients.

Dr Anna Waterhouse, head of USYD's Cardiovascular Medical Devices Group, is investigating how the material properties of blood contacting medical devices influence blood clot formation. Material surface chemistry, hydrophobicity, roughness and charge can determine the dynamics of protein adhesion onto the device which, in turn, dictates the downstream events in thrombosis.

'By understanding the blood clotting processes on materials better, we can potentially give patients drugs to break down clots or avoid scenarios where blood clots break off from medical devices,' said Dr Waterhouse. 'Ideally, we aim to modify the material surface properties of medical devices to significantly reduce clotting risks and reliance on anti-clotting therapies.'



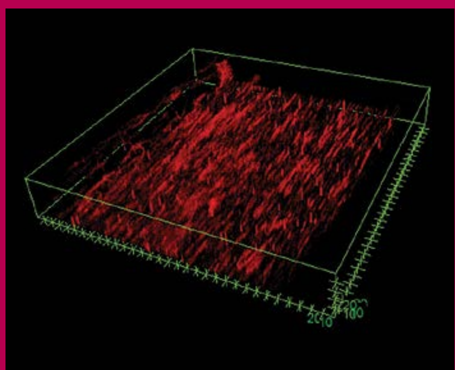
Currently, researchers study material and blood flow effects by constructing flow circuits from plastic tubing and pumps. Because these channel loops require large volumes of blood (30- 40 mL) to operate, the continual recruitment of human volunteers to donate blood is needed to obtain a sufficient blood supply to run experiments.

Keen to develop a microsystem to mimic blood flow conditions inside a medical device that would also allow her team to manipulate material properties for their experiments, Dr Waterhouse contacted the microfluidic experts at ANFF-SA. Her timing was impeccable, with Dr Waterhouse discovering that ANFF-SA's free Microengineering School could provide her research assistant and students with the innovative fabrication skills her team required to develop their novel microfluidic device.

Dr Waterhouse also learned that ANFF-SA's expertise in Computational Fluid Dynamic (CFD) modelling could help optimise the design of their microfluidic device prior to fabrication and inform their experimental parameters. The team's design requires much smaller blood volumes (5 mL) than conventional test systems. In addition, operators can control flow through the device and precisely determine blood flow dynamics within the system, including flow rate and shear rate. Since shear rate is a key factor in clot formation, Dr Waterhouse's microdevice can mimic the shear conditions of different medical implant scenarios.

'With ANFF's support we have demonstrated that material wettability plays a role in influencing the density of the blood clots which form,' said Dr Waterhouse. 'Our research suggests we can modify the material surface properties to modify the clot structure formed, so materials could be made to reduce the risk of clots breaking off and lodging in other organs.'

This is a clear example of the strength of the ANFF network, with the team using the training from ANFF-SA and accessing ANFF-NSW facilities and USYD's Research and Prototype Foundry to enable Dr Waterhouse's group to optimise their manufacturing process and rapidly prototype their microfluidic device with access to cutting-edge mask aligners and photolithography equipment.



3D RENDERING OF A BLOOD CLOT FORMED UNDER FLOW USING A NOVEL MICROFLUIDIC DEVICE.
Credit: doi.org/10.1002/adhm.202100988

PREVENTING UNNECESSARY EMERGENCY C-SECTIONS

VitalTrace is working to improve the safety of mothers and babies during childbirth, some of our most vulnerable and youngest patients.

At the core of labour is a mother, her baby, her obstetrician or midwife, and the hospital system. Success is measured by a safely delivered baby. Monitoring the baby's status during the labour progression is standard practice, and the current system hasn't changed in over 60 years. Cardiotocography (CTG) monitors the baby's heart rate and the mother's uterine contractions to create a continuous readout. CTG devices consist of external sensors belted around the mother, intruding on what is hoped to be a natural birth experience. 90% of mothers are routinely monitored electronically via a device such as this. In 30% of patients, an additional electrode is directly applied to the baby's scalp to directly track its heart rate when a CTG isn't providing a clear readout.

A key flaw in this widely used technique is that CTG interpretation is fundamentally subjective. In some traces, the baby's heart rate clearly indicates that it is in no distress, and labour can proceed with vaginal natural delivery. At the opposite end, foetal heart rate rhythm is abnormal to such an extent that doctors are confident the baby is in trouble. These babies are delivered via emergency caesarean section (C-section).

However, up to 84% of CTG traces fall somewhere in between and are not conclusive (Category II traces). Interpretation is left to the doctor's discretion, and doctors are increasingly opting for emergency C-sections rather than risk vaginal delivery. In recent years, the rate of C-section delivery in Australia has been increasing, with 36% of all women giving birth via C-section.

Alarmingly, CTG monitoring has a 70% false positive rate, so emergency C-sections are performed on thousands of healthy mothers and babies. With a 300% greater risk of maternal death because of unnecessary C-sections, inaccurate readings can carry large consequences.

Reliable information about foetal blood oxygenation is possible through a laboratory diagnostic: a time-intensive, invasive test for lactate levels in a blood sample taken from the baby's head. Lactic acid is produced by tissues when there is insufficient oxygen available; therefore, blood lactate level is an objective indicator of foetal status. High lactate levels mean the baby is in true distress. However, the diagnostic test takes 20-30 minutes to complete, during which time a labour situation can change dramatically. In addition, foetal scalp lactate testing is not a widely available diagnostic tool.

CTG continuously monitors labour but is highly inaccurate; foetal blood lactate testing is accurate but not continuous. A critical unmet need is the lack of real-time, reliable data about babies' oxygenation and wellbeing during childbirth.

Taking inspiration from real-time diabetic glucose monitoring devices, the Perth-based company VitalTrace has developed a revolutionary wearable device that continuously and accurately measures the baby's lactate levels while preserving the natural flow of labour. Its novel sensor goes on the baby's scalp and continuously measures oxygen and lactate. The sensor is connected to a small wearable electronic unit on the mother's leg, and real-time data is transmitted wirelessly to a bedside monitor.

When Dr Michael Challenor and Dr Arjun Kaushik launched VitalTrace in 2020, their brilliant idea needed logistical and fabrication support to make their vision a reality. Their biosensors need to be manufactured and fabricated under sterile conditions – but cleanroom and fabrication equipment are not widely available in Perth. Partnering with ANFF-WA and Prof. Sharath Sriram at RMIT University, VitalTrace's technology is now being scaled up as a fit-for-purpose device to be manufactured in Australia for a global market.

VitalTrace has completed pre-submission meetings with both the US FDA and the AUS TGA. The FDA is evaluating its DelivAssure device through its breakthrough designation program (BDP), recognising that getting VitalTrace's ingenious device successfully to market will have a major impact on birthing mothers and their babies and may eventually replace CTG as the standard of care for labour monitoring.

PROTECTING THE PROSTATE

UNSW researchers Yanfang Wu and Justin Gooding's revolutionary nanopore blockage sensor technology lowers the detection limit of PSA screening, allowing earlier detection of prostate cancer.

In Australia, one in six men is likely to be diagnosed with prostate cancer by the age of 85. In its early stages, the growing tumour is confined within the prostate and does not usually cause symptoms, often developing undetected.

By Stage IV, the cancer has metastasised to other parts of the body. Only in this stage do we observe noticeable symptoms like painful urination, fatigue, and bone pain.

Like most cancers, survival is higher if the cancer is detected earlier rather than later. In 2019, the *British Medical Journal* reported that the 5-year survival rate for prostate cancers detected in Stages I – III is near 100% but declines steeply to 47.7% if detected in Stage IV.

If there are few initial symptoms, how can we detect early-stage prostate cancer? Doctors use the PSA test to measure blood levels of prostate-specific antigen (PSA), a protein made by both normal and cancerous prostate cells but in greater quantities in cancerous cells. Since PSA levels rise throughout tumour progression, regular PSA screening can detect changes in a man's PSA production, prompting further cancer screening.

However, the PSA test is not always accurate, especially in the earliest stages when very little PSA is being produced and available in circulation. Existing detection technologies seldom reach the low concentrations that are clinically relevant.

An unmet need in the field of biosensors is to develop technologies that selectively detect cancer biomarkers at ultralow concentrations. Recently, University of New South Wales (UNSW) researchers Dr Yanfang Wu and Scientia Prof. Justin Gooding of the ARC Centre of Excellence in Convergent Bio-Nano Science and Technology and the Australian Centre for NanoMedicine have developed a new nanopore blockade sensor for biomarker screening.

Typically, a nanopore sensor detects individual molecules moving through a membrane-embedded, nanoscale pore. Molecular passage through the nanopore causes detectable changes in electrical conductance of the nanopore. However, many nanopore sensors are not selective, responding to all molecules small enough to pass through the pore. Non-selectivity is a problem when dealing with complex biological samples like blood.

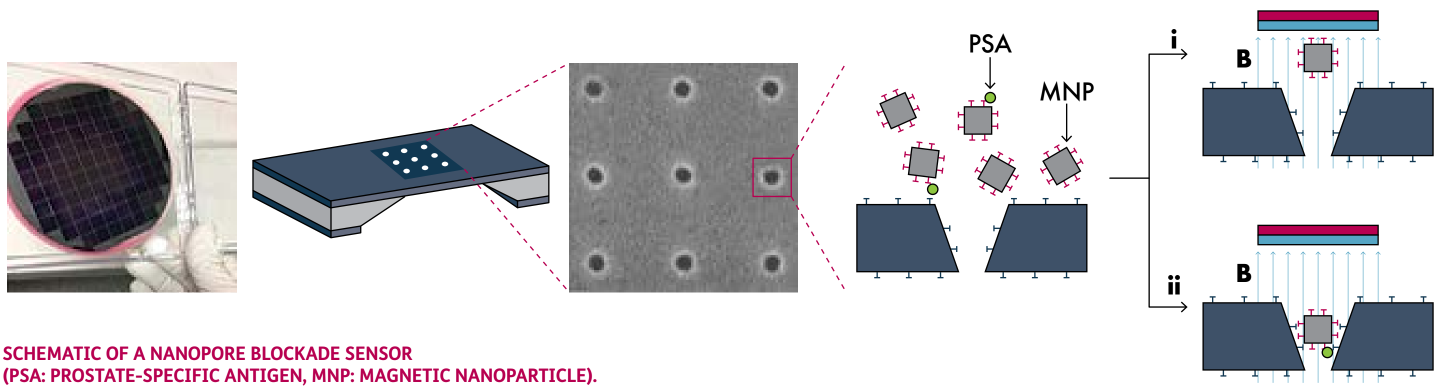
The Gooding research group has modified nanopore sensor technology to actively and selectively screen a specific biomarker. Their system employs devices containing an array of nanoscale pores and tailored magnetic nanoparticles (MNPs).

Both system components are modified with proteins that bind to PSA. These anti-PSA MNPs will capture the PSA molecules present in a blood sample. The higher the PSA concentration, the more MNPs will be bound to their targets.

The Gooding Group's device can actively shuttle the PSA-bound MNPs to the anti-PSA-modified nanopore array by applying a magnetic field. Once brought to the array, a MNP cannot move through the nanopore, blocking it instead. With both surfaces modified to bind to PSA, a sandwich-complex forms in the nanopore such that a bound MNP cannot be removed when the magnetic field is reversed to pull the unbound nanoparticles out of the array. Blocked nanopores generate large changes in transmembrane current relative to the number of blocked pores.

With PSA-specific binding, other biomolecules will not cause nanopore blockage. As a result, false signals are avoided, and better specificity is achieved. In addition, a MNP nanopore blockade sensor actively brings PSAs to the nanopore by the action of magnetic force rather than relying on passive diffusion, which greatly reduces analysis time. Most importantly for early cancer detection, the nanopore blockade sensor is sensitive to a single molecule and achieves the detection of PSA at sub-femtomolar (fM, 10^{-15} moles/litre) levels directly from complex biological samples.

ANFF-NSW has provided fabrication and technical support for the development of this nanopore blockage sensor device for the last decade. With ANFF's assistance, Prof. Gooding and his colleagues have created a revolutionary system that can measure PSA at ultralow concentrations, showing great promise for the earlier detection of prostate cancer. Future work will expand the use of this technique to detect other medically important biomarkers.



SCHEMATIC OF A NANOPORE BLOCKADE SENSOR
(PSA: PROSTATE-SPECIFIC ANTIGEN, MNP: MAGNETIC NANOPARTICLE).

ENERGY AND ENVIRONMENT

In the coming decades, Australia will continue to face unprecedented challenges due to changes in our climate and environment. Rapid environmental changes due to climate change and the continued degradation of our land and water ecosystems demand solutions that will reduce or avoid negative impacts on the biosphere and human societies. Increasing consumption of resources and the impact of over-consumption on societies and economies give urgency to the adoption of sustainable development practises.

Some of Australia's National Research Infrastructure is already directed towards these challenges, but there is urgent need to increase the pace and scale of research activities. Technological innovation is critical to meeting the challenges of the United Nations' 2030 Agenda for Sustainable Development including available water and sanitation, food security, sustainable agriculture, sustainable consumption and production patterns, and affordable clean energy.

In the Energy and Environment section, we feature stories across several sectors of the NRI Roadmap, including Food and Beverage, Recycling and Clean Energy, and Environment and Climate.

WEARING WASTE

The ANFF-Vic hub at Deakin University is providing the tools and expertise to convert old clothes into new fashion and substantially reduce the waste produced by this industry.

Through modern consumption patterns, society discards an ever-increasing amount of material waste. In particular, the textile industry is a significant consumer of fresh water, pesticides and land.

Fast fashion has exacerbated the negative impact of textile production. These cheap, stylish, mass-produced garments appeal to shoppers because they are affordable and trendy. However, these products aren't built to last and almost immediately go out of style. As a result, these clothes are quickly discarded, piling up in landfills. In fact, 85% of all textiles go to dumps every year, and the average Australian discards 27 kg of textile waste each year to landfill.

Such behaviour is ultimately unsustainable, and the need to institute a more Circular Economy in the textile industry is becoming an ever-increasing priority. A circular economy system reduces material use, redesigns materials to be less resource intensive, and recovers and regenerates valuable materials from waste as a resource for manufacturing new materials.

In response to increasing demand for solutions to these challenges from industry, government, and society at large, the Institute for Frontier Materials (IFM) and Deakin University have instituted a new research priority around Circular Economy with textiles as a key focus. To facilitate this demand, with the support of ANFF, IFM has launched the ARC Research Hub for Future Fibres, expanding its facilities for innovative development in textile production.

A case study for the potential of this facility is a partnership with Australian biomaterials company Nanollose, whose aim is to develop sustainable textiles, replacing current use of unsustainable wood pulp with bacterial cellulose produced via the fermentation of wastes and by-products from the food and agricultural industries. Its 100% Tree-Free Nullarbor™ lyocell fibre was made at Nanollose's partner's R&D facilities in India and spun into yarn using standard industrial yarn-making equipment at the ARC Research Hub for Future Fibres. The resulting Nullarbor™ yarn spun at IFM was provided to Victorian knit innovation studio, Knovus, to construct a 3D knitted garment from the yarn with zero fabric waste. This collaboration demonstrated that innovative sustainable fibre production can work seamlessly with existing industrial equipment to produce amazing new fabrics.

Currently, ANFF and IFM are incorporating more capabilities to further develop the ARC Research Hub for Future Fibres. ANFF's investment will provide more opportunities for those wanting to develop new fibres and turn them into fabric. The new capabilities will allow for more of the fibre processing to be done in one place and at scales that are more attractive to potential industry partners.

By working with the expertise at IFM and partners such as Nanollose and strategically acquiring tools that are fit for purpose from the industry point of view, ANFF can provide value to the onshore textile manufacturing industry and ensure that sovereign capabilities are not lost to Australia. In this way, Australia can become a leader in the conversion of a wasteful industry to one that is sustainable and circular.

BETTER FARMING AND GARDENING THROUGH DRONE TECHNOLOGY

Australian company Magic Wavelength is making a significant difference in sustainable agriculture and home gardening through their AgTell and PlantTell plant health sensors.

According to the United Nations, in 2020, over 30% of the world's population – a staggering 2.4 billion people – were moderately or severely food-insecure, lacking regular access to adequate food.

While we may think that food insecurity plagues only developing nations, inequality of food access is a problem even in developed nations like Australia. The Australian Institute of Family Studies (AIFS) reports that 4-13% of Australians lack food in the quantity and quality needed for a healthy life. The situation is more dire for the indigenous population in which 22-32% experience food insecurity.

The COVID-19 crisis, global supply chain disruptions, and climate change have pushed food insecurity rates even higher. Our growing food crisis demands innovative technologies that support sustainable agriculture and empower small farmers globally and home gardeners locally.

Magic Wavelength is an early-stage agriculture technology (AgTech) company focused on the development of novel sensors and instruments for non-invasive ground-based or airborne (drone) vegetation monitoring. Its core mission is to create innovative, low-cost products that provide growers with vital information that can be used to determine plant health.

Two main indices track plant health by measuring light reflectivity from vegetation. When sunlight strikes a plant leaf, some wavelengths are absorbed while others are reflected. Healthy plants absorb most of the visible light spectrum. The Normalised-Difference-Vegetation-Index (NDVI) determines general plant health based on relative reflection of visible and near-infrared (NIR) light. Healthy plants reflect much of the NIR spectrum. Unhealthy plants reflect more visible light and less NIR. NDVI index values can tell farmers when crops need fertilisation, enabling them to optimise the use of precious resources and minimise overfertilisation.

A second index, the Normalised-Difference-Water-Index (NDWI), measures plant water stress. The NDWI is similar in methodology but is based on NIR and short-wave infrared (SWIR) wavelengths that indicate changes in leaf water content. The NDWI can determine when crop irrigation is needed.

The ability to determine crop health is critical for the world's 570 million farms and over a billion homes having some form of gardening activity. The underlying science for remote spectral sensing is well established, and remote sensing technology has been pivotal in improving yields for larger-scale agricultural farms and businesses.

But access to remote sensing data comes at a price, one that is out of reach of smaller farmers and growers, especially in remote or less affluent regions.

Credit: Dmitry Dreyer

By partnering with ANFF-WA, Magic Wavelength gained access to the fabrication and characterisation tools needed to successfully create, test and troubleshoot an innovative, compact, low-cost product that combines the latest advances in sensor technology, complementary optics, and smart processors. The company's disruptive technology will place affordable sensing capability into the hands of growers that will benefit most.

For the agricultural sector, AgTell is a revolutionary drone-based solution which provides farmers access to remote spectral sensing of their farmlands. AgTell can measure both NDWI and NDVI and translates that data into a diagnosis on the health of the crop. AgTell drones will allow farmers to directly scan and diagnose their fields, taking the guesswork out of fertilisation and irrigation.

For home gardening, Magic Wavelength's consumer product, PlantTell, is the world's first handheld portable plant sensor that directly provides intelligence about plant health. When placed on an indoor or outdoor plant leaf, PlantTell will measure the reflection of the specific wavelengths needed for the NDWI and NDVI and immediately indicate to the gardener if the plant needs feeding or watering. This information can then be recorded and shared with others through Magic Wavelength's PlantTell App, creating an active and engaged social community of gardening enthusiasts.

Magic Wavelength's compact, low-cost instruments will provide farmers and gardeners the best possible outcomes for plant health and productivity with the optimum use of precious resources such as fertilisers and water.

To secure our local and global food supply, sustainable agriculture is the solution. There are many elements of traditional farmer and gardener knowledge that, enriched by the latest scientific knowledge and technology, will support productive food systems through sound and sustainable land, soil, water, and nutrient management.

CRYSTAL-CLEAR WATER FOR ALL

Global water stress demands new technologies for the purification of different water resources.

The United Nations 2030 Agenda for Sustainable Development lays out 17 goals to obtain peace and prosperity for all people and the planet, chief among which is a commitment to clean water and sanitation. We need to ensure clean water and sanitation while maintaining the health of water-related eco-systems and providing relief for over 733 million people living in countries with high and critical levels of water stress.

ANFF plays a critical role in supporting cutting-edge research programs that imagine innovative solutions to water purification and water treatment, helping researchers turn their ideas into accessible products that will directly impact people's lives around the world.

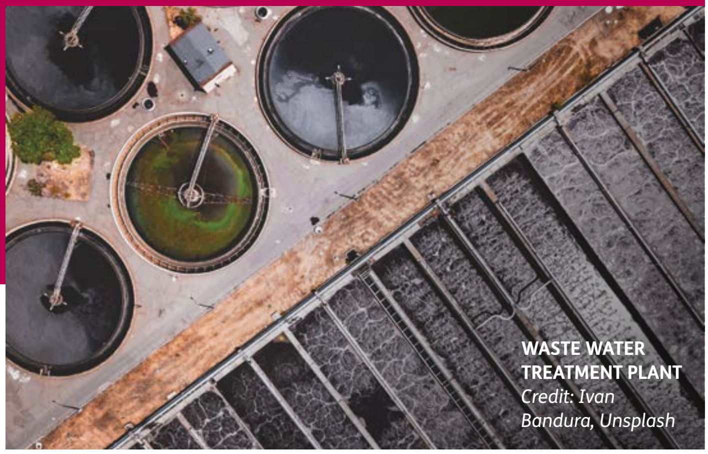
WATER VAPOR RISING FROM THE 3D SOLAR EVAPORATOR SURFACE.

A super-efficient, portable 3D solar evaporator developed by University of South Australia researchers will enable vulnerable communities to access reliable and affordable fresh drinking water from previously unusable water sources.

Using sunlight as an energy source, A/Prof. Haolan Xu and Dr Xuan Wu from UniSA's Future Industries Institute in collaboration with ANFF-SA have developed a novel solar evaporation technique to derive fresh water from sea, brackish or contaminated water. Current solar evaporators are rather energy-inefficient, with 10 to 20% of incoming energy wasted in warming the bulk water and surrounding environment rather than evaporating the water.

Easy to set up and made of materials almost entirely sourced from a local supermarket, the key to the technology's heat absorption is in the innovative design of the 3D evaporator. Their device includes a photothermal fin-like structure that sits on the water surface. Constructed of fabric material, water is transported via wicking through the fins to the top evaporation surface. At this top surface, sunlight is converted to heat, rapidly evaporating the thin film of water.

Mimicking the ocean-surface evaporative processes of the natural water cycle, their 3D solar evaporator provides clean water solutions that are cheap, free to run, and require minimal maintenance. Its heatsink-like evaporator not only effectively prevents heat energy loss from the evaporation system, but it actually extracts a large amount of energy from the bulk water and surrounding environment to boost evaporation.



WASTE WATER TREATMENT PLANT *Credit: Ivan Bandura, Unsplash*

At current rates, in 2030 2.8 billion people will lack safely managed sanitation. New membrane technology developed by Deakin University researchers will revolutionise the filtration capabilities of wastewater treatment plants.

Wastewater is a polluted form of water generated from human activity and storm runoff. Through a combination of various physical, chemical and biological processes, a wastewater treatment facility removes contaminants from the water to create purified water that can be reused or released into the surrounding environment.

Particle filtration, which separates out solids larger than one micron, is one of the first treatment steps. However, particle filters are not sufficient to obtain required purification levels. To obtain the highest water quality, membrane filtration systems are used due to their high separation efficiency. Obviously, the material composition used in the membrane plays a critical role during the separation process since it governs the interactions between the membranes and different water pollutants. Membrane interface engineering is therefore a powerful approach to tailor the function of the membrane and optimise the separation performance.

Ahmed Rashed, a PhD student of Prof. Joselito Razal in Deakin University's Institute for Frontier Materials (IFM), in collaboration with Lintec of America, Inc.; the Melbourne Centre for Nanofabrication and ANFF-Vic, uses atomic layer deposition (ALD) to redesign and fine tune the properties of filtration membrane surfaces, including thickness, pore size and surface charge. IFM's innovative tin (IV) oxide-carbon nanotube (SnO_2-CNT) technology extends membrane function beyond simple separation to catalytic, anti-viral, and self-cleaning properties. Their novel membranes simultaneously separate and degrade chemicals such as pharmaceuticals and viruses in water outflow without diminishing filtration performance.

The Razal group's use of ALD to tailor and manipulate CNT membrane surfaces will shed light on the engineering of high-performance catalytic membrane treatment reactors, taking us one step closer to fulfilling the UN Sustainable Development goals with low cost, high-efficiency water purification.

2D MATERIAL MAKES ITS MARK ON THE FACTORY FLOOR

Sicona Battery Technologies Ltd has purchased a world-first, scalable, edge-functionalised graphene production method from researchers at the ARC Centre of Excellence for Electromaterials and ANFF-Materials.

Graphene, a single layer of carbon atoms bounded tightly together in a repeating honeycomb pattern of hexagons, is a very promising nanomaterial due to its exceptional properties. It is one of the thinnest, yet strongest, materials on Earth. An extraordinary conductor of both heat and electricity, graphene is optically transparent, chemically resistant and biocompatible.

Graphene, with its unique combination of physical and electronic properties, has the potential be used in a variety of technological applications and devices and radically impact many areas such as energy harvesting and storage, sensing, electronic devices and polymer composite technologies.

While the possible uses of graphene seem limitless, obtaining graphene in a processible form that can be fabricated into devices and composites is a major challenge. The very structure that gives graphene such extraordinary properties makes it difficult to produce and limits its application. The large single sheets of graphene that can be produced from graphite or other carbon sources by physical or chemical methods are poorly soluble in most solvents and are prone to reassemble into insoluble graphite-like particles.

Most current graphene fabrication methods can create a few grams of graphene in the laboratory, but they have proven too expensive to scale up to industry relevant amounts. The technical advances that can be made possible with graphene will only be achieved if there is a manufacturing method that can make graphene in massive amounts – cheaply. The lack of scalable, processable forms of graphene along with ways to fabricate these forms into material structures and devices has hindered its widespread application.

Researchers from the University of Wollongong ARC Centre of Excellence for Electromaterials Science (ACES) and ANFF-Materials, led by Prof. David Officer and Distinguished Prof. Gordon Wallace, have developed a patented, scalable, graphite-to-graphene process that allows them to chemically modify only the edges of the graphene sheets to give a highly conductive edge-functionalised graphene (EFG).

The resulting extensive edge functionalisation of the EFG sheets not only affords the graphene unprecedented solubility while retaining many of the physicochemical properties of pristine graphene, but it also prevents the reassembling of the EFG into unwanted graphite particles.

What results is a highly processable and remarkably versatile graphene that can be used as a powder or dispersion, paste, or even dough and can readily disperse in water or a wide variety of polar and non-polar organic solvents. Furthermore, the edge functional groups provide enhanced chemical reactivity for composite formation, ion transport and catalysis that can be exploited in specific applications.

As a result of this unique processibility, NSW start-up Sicona Battery Technologies Ltd (Sicona) purchased the EFG patents from the University of Wollongong in 2021 for utilisation in their battery technology. As part of the deal, Sicona signed a two-year research agreement with ANFF researchers to scale up the EFG fabrication process for commercial production as well as further explore the potential of EFG as a battery material.

Yes, the brilliant researchers at ACES and ANFF have developed an ingenious EFG production process that is bringing graphene from the laboratory bench to the factory floor. While that achievement is astounding in its own right, these researchers have developed a graphene that isn't just a graphene – their new type of EFG is so much more.

With a material that holds onto the unique combination of properties found in graphene, their edge functionalisation adds customisable chemical and electrical features that will expand the possible uses of this material. From batteries to coolants, water filtration to carbon capture, biosensors to nanomedical devices, EFG will ensure that graphene will truly take its place as a material impacting and improving many aspects of our everyday lives.

EDGE-FUNCTIONALISED GRAPHENE IN DIFFERENT FORMS.

A BREATH OF FRESH AIR

Researchers at Australia National University have developed a miniaturised gas sensor to continuously monitor air quality in our vehicles.

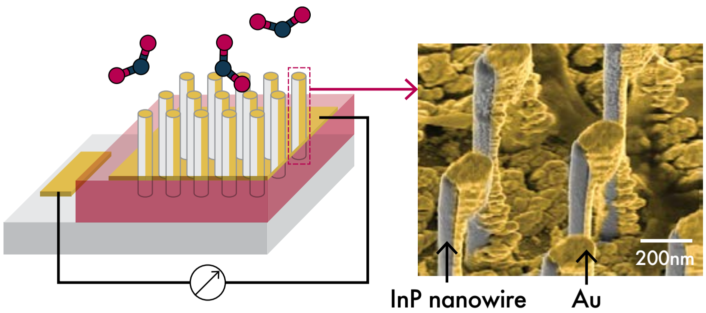
Well known for its clean air, Australia ranks among the top 10 countries globally in terms of overall air quality. However, even at low levels, air pollution can negatively impact our health. Although particulate matter from dust storms and bushfires causes extreme air pollution events regionally, motor vehicles and road traffic are the main generators of pollution in urban areas.

Sitting in traffic can literally be a threat to your health. Gasoline-powered vehicles produce the pollutant nitrogen dioxide (NO_2) and are the highest contributors to NO_2 emissions in Australia. Exposure to this gas can increase a person's vulnerability to, and the severity of, asthma and respiratory infections and can irreversibly damage the human respiratory tract. Long-term exposure will reduce a person's sense of smell and can cause chronic lung disease.

Even drivers of electric vehicles (EVs) can be exposed to high levels of this toxic gas. While sitting in traffic, exhaust from other cars can enter and become trapped within a vehicle. In daily traffic, NO_2 levels inside a car can be 10 times higher than the air outside.

The levels of the major air pollutants, such as carbon monoxide, sulphur dioxide, NO_2, ozone and particulate matter, are monitored by the Australian government. This information is reported on weather and air quality apps and websites and in daily news. However, the numbers you see are not reporting the air quality in your vicinity. The equipment for measuring air pollutants is stored in air quality monitoring stations (AQMS), so the air quality report is for the station's location. In addition to poor geographical resolution, our current air monitoring systems rely on specialised large-footprint instruments that require trained personnel to operate. Air sampling is not continuous, and instrument processing causes a delay in getting the analysis. Real-time, local measurement of NO_2 pollution is not available in a crucial location – our vehicles.

Chemiresistive sensing is one of the most promising technologies for portable and miniaturised chemical sensing. Chemiresistive materials experience changes in electrical resistance in response to changes in the nearby chemical environment. Recently, there have been growing efforts to develop microchip-based chemical sensors operating at room temperature with high sensitivity, selectivity, spatial and temporal resolution, long-term stability, and cost-effectiveness.



NO_2 ADSORPTION ONTO A VERTICAL INDIUM PHOSPHIDE (InP) NANOWIRE ARRAY.

Shiyu Wei, a PhD student of Prof. Lan Fu in The Australian National University's Department of Electronic Materials Engineering, has taken on this challenge, developing highly performing miniaturised gas sensors containing chemiresistive indium phosphide (InP) vertical nanowire arrays. Chemical adsorption of NO_2 onto the InP surface increases the wire's resistance, resulting in measurable change in the electrical current. Nanostructuring of the InP creates a high surface-to-volume ratio that allows more efficient gas adsorption and resistive change for greater sensing performance.

Working hand in hand with Dr Kaushal Vora and the staff of ANFF-ACT, Ms Wei optimised various parameters of her design, including array geometry and nanowire diameter and length. Under Dr Vora's guidance, she mastered the art of fine tuning her fabrication method and troubleshooting her design to successfully produce one of the world's best chemical sensors that selectively detects NO_2.

The Fu research group's proof-of-concept device is a game changer for air pollution monitoring, providing local data in real-time with outstanding selectivity. Current instruments have limited sensitivity at parts per million. Their chemiresistive InP gas sensor can detect amounts as little as 3.1 parts per billion, which is necessary to accurately measure repeated exposures to this chemical at the relevant concentration levels.

At less than 5 mm x 5 mm in size, this miniaturised sensor has the potential for integration into the on-board electronics in our vehicles. Providing real-time data on NO_2 levels in a car's interior will provide drivers with critical information to limit their exposure to this toxic gas with simple actions such as recirculating the air and closing the windows.

COLOURED GLASS FOR A MORE SUSTAINABLE FUTURE

EZY-GLAS provides eco-friendly coloured glass products for use in glass art, printing and other high-value applications where product identity, safety and quality are prerequisites.

Throughout human history, the discovery of new materials has propelled human societies through successive stages of advancement – the Stone Age, Bronze Age and Iron Age. But what material now underpins our modern society?

Look no further than the glass materials found all around us – stained, moulded, blown, paned, mirrored, display, fibre, foldable, bioactive, and the list goes on. We are in the Glass Age.

In recognition of the importance of glass in modern society, the United Nations has designated 2022 as the International Year of Glass. Glass making and glass materials innovation have driven progress in all areas of our lives including architecture, art, food safety, optical communications, sustainable energy, mobile electronics, reusable and recyclable packaging, circular economy and medical devices.

From the earliest glass artifacts made in 3100 BC Egypt, the process of creating glass begins with melting raw materials, such as sand (silicon dioxide), soda ash and limestone, to high temperatures. Glass is shaped when it has a viscosity between that of a liquid like water and that of a solid like salt and moulded into the desired product. At its most fundamental level, glass is a nanotech material. Its fabrication and application begin and finish with understanding physical and chemical phenomena at the nanoscale.

Colourants added during the glass making process produce the vibrant diversity of glass colours around us. However, some colours are more difficult or troublesome to create. Commercial glasses/enamels of warm colours (e.g. oranges and yellows) mostly contain toxic heavy metals like lead and cadmium. Incorporating toxic materials into the glass-making process significantly increases manufacturing costs due to the necessity of protecting the environment and the health and safety of glass workers. The expensive toxic process and waste control systems needed to sustain the business under increasingly stringent environmental regulations are an extra burden for the industry.

YUNLE WEI AND HEIKE EBENDORFF-HEIDEPRIEM MAKING A CUP TOGETHER FROM MOLTEN GLASS WITH INCORPORATED GLAS-BASED COLOURED GLASS PIECES.
Credit: Evan Johnson

Taking advantage of ANFF-Optofab's glass manufacturing capabilities, Yunle Wei, Jiangbo Zhao and Heike Ebendorff-Heidepriem at the University of Adelaide have invented a nanotech solution to impart warm colours into any oxide-based glass. Their GLAS technology employs non-toxic and biocompatible gold and silver nanoparticles (NPs). At the nanoscale level, gold NPs are not gold in colour nor are silver NPs silver. NP colour is a size-dependent property, meaning that NP size determines the colour that results. GLAS technology forms these NPs in a highly controlled way to obtain different particle sizes. By controlling NP size, GLAS technology can produce a broad, non-toxic, colour palette.

In 2020, these inventors established the start-up company EZY-GLAS Technology Pty Ltd to commercialise their GLAS technology. EZY-GLAS will be able to mass-produce eco-friendly glasses/enamels of warm colours with unique light-manipulating properties, as well as of other colours in conjunction with selected colorants. Their coloured glass products are in the form of powders or paste that can be applied to glass, ceramics, metal or any base material that will withstand a fusing step to burn-in the coloured glass particles into the base material for decoration, labelling and anti-counterfeiting.

EZY-GLAS products empower glass makers and manufacturers to move away from the use of heavy metals in their glass making processes, improving health and safety conditions for their workers and protecting the environment from toxic waste. In addition, GLAS-based glasses and enamels are fully recyclable, supporting the sustainable production, use and reuse of glass products.

GLAS-based coloured glass has been successfully employed by local glass artists at the Jam Factory to make glass artefacts. EZY-GLAS is also exploring other market opportunities such as jewellery; decoration and art; glass & ceramic based packaging for food, beverage, cosmetics, perfumery and pharmaceutical drugs; 3D glass printing and more.

TRANSFORMATIVE MATERIALS

The NRI Roadmap lays out the coming challenges in Frontier Technologies and Modern Manufacturing (FTMM) – to develop transformative technologies that will add value to existing manufacturing, create new disruptive industries, commercialise socially beneficial research outcomes and enhance national manufacturing capability. Transformative materials create important and lasting improvements in technology, manufacturing, materials discovery and the human experience.

The researchers and companies featured in this Casebook section exemplify transformation: innovative materials that will propel the adoption of clean energy, processing methods that allow us to integrate emergent technology into current manufacturing processes, integration of robotics and AI into fabrication processes to revolutionise the way we discover new materials, and the ingenious use of materials to challenge human perception.

ANFF's micro- and nanofabrication infrastructure empowers our clients to create transformative materials with superior and customised attributes, improve efficiencies in production and value chains, and continue their excellence and innovation in research and development.

MIRRORMIRROR

Artist Deirdre Feeney's creative application of microfabrication processes in her visual artwork MirrorMirror led to novel artistic outcomes and the necessity to push the boundaries of ANFF-SA's surface polishing capabilities.

Artists are increasingly collaborating with scientists and engineers to problem solve and creatively apply STEM methodologies into artworks. University of South Australia Contemporary Art lecturer Deirdre Feeney's cross-disciplinary engagement with ANFF to develop components for an optical image system artwork allows her to focus the viewer's attention to technologically mediated visual experiences.

Dr Feeney works with optical image systems as tools to explore constructed reality, exposing the components and the mechanisms of how we see what we see. Today, people have a very passive experience interacting with imaging technology like mobile phones and displays. As optical technology advances and the scale of components decreases, we don't think about how these images are generated and how our visual experience is manipulated. It's invisible to us.

Based on artist-engineer Charles-Émile Reynaud's nineteenth century application of optical mechanics to create his animated moving picture shows, Dr Feeney's MirrorMirror creates moving pictures using modern optics, electronics and digital fabrication – revealing the components, materials and mechanism of the apparatus so that the viewer can engage with modern visual technology in a tangible way. With her artworks, Feeney poses the question: 'How it is we're seeing what we're seeing?'

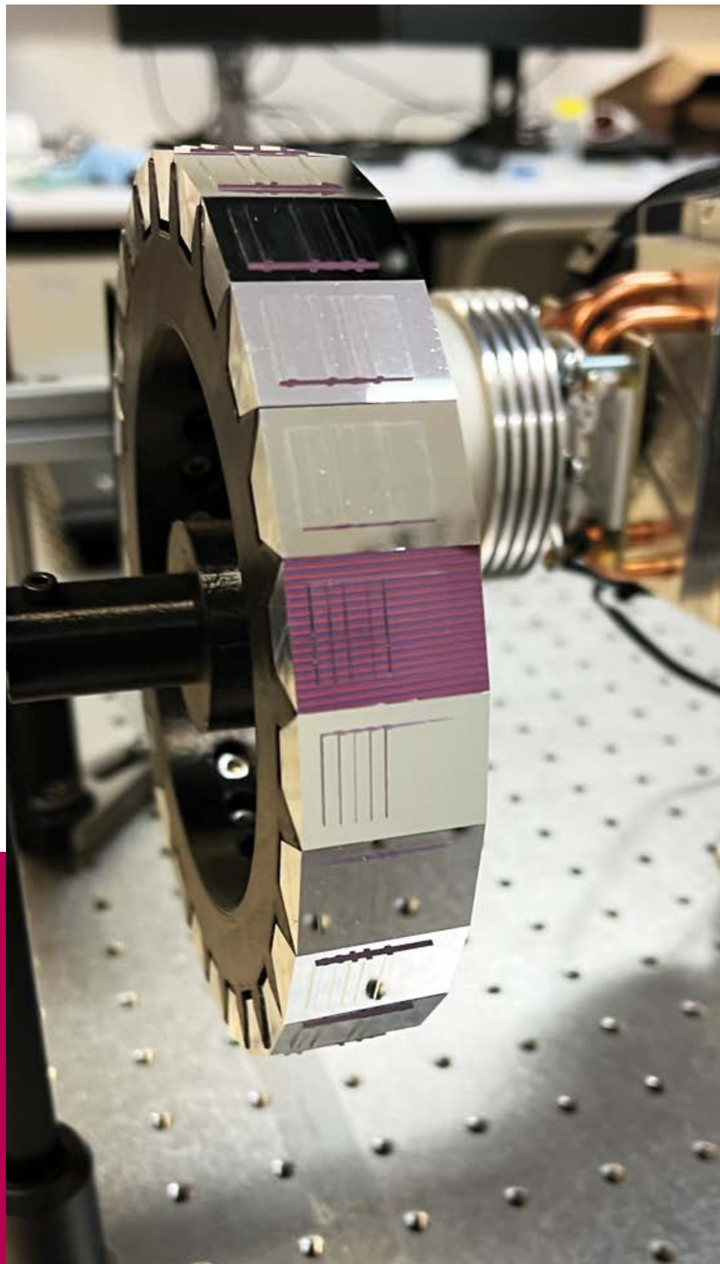
Reynaud's traditional system incorporates a plane mirrored polygon and series of matching image frames rotating to establish the illusion of movement in the projected image. MirrorMirror explores possibilities for creating moving images using a single image source and series of 3D-patterned mirrors.

Funded by an Australian Network for Art and Technology (ANAT) Synapse Residency Grant and facilitated by the micro-manufacturing expertise at ANFF, Dr Feeney's creative project began by using ANFF's nano-lathe at the ANU Research School of Physics in collaboration with Dr Geoff Campbell (ANU). Next, Dr Feeney and ANFF micromachining expert Mark Cherrill worked together to apply 3D-modelling and micro-milling techniques to develop a highly polished mirrored polygon as the central component of her optical moving image system. In each mirror, facet bands manipulate light in a different way to generate the illusion of 3D movement from a single 2D image source of parallel lines.

ANFF's flagship Kira SuperMill 2M was the right tool to fabricate the high precision mirrors. However, the degree of surface roughness needed to put an image in motion had not yet been accomplished by the instrument. Mr Cherrill expanded the machining capability of the Kira SuperMill by employing a mono crystal diamond cutting tool to achieve the ultra-precision cuts and optically polish the mirror facets to a surface roughness of 7nm, a ten-fold improvement in surface roughness manipulation.

For Dr Feeney, through the fabrication process she's been able to tangibly understand how materiality can control the depth and movement of the image, a realisation she hopes to impart to audiences through her artworks.

As an outcome of the collaboration, ANFF-SA can now machine other devices requiring ultra-precision finishes in-house. ANFF's new capabilities in machining high aspect ratio moulds are being integrated into research and industry projects focused on developing medical applications for IVF, circulating tumour cells, sperm separation and cardiac bioengineering. In addition, the surface finish achieved with the mono crystal diamond cutter is so superior that ANFF-SA is now investigating potential collaborations with researchers and industry working in space optics.



A HIGHLY POLISHED MIRRORED POLYGON IS THE CENTRAL COMPONENT OF DR FEENEY'S MIRRORMIRROR OPTICAL MOVING IMAGE SYSTEM.
Credit: Deidre Feeney

USING AI TO CAPTURE SUNLIGHT

Through the innovative use of robotic automation and AI learning, a new Monash University 'toolbox' is available to develop, test, characterise and optimise new materials for photovoltaic cells.

The effects of climate change are calling for a rapid transition from fossil fuels to renewable energy sources. The development of new materials for energy generation and storage will drive this transition. Key to these efforts is the optimal design of the material systems involved in these devices and products. With a seemingly infinite set of materials and design possibilities, finding the best system for a particular application is like searching for a needle in a haystack.

Monash University Prof. Udo Bach, leader of the Australian Centre for Advanced Photovoltaics (ACAP) Monash Node, has developed the High Throughput Solution-Processable Photovoltaic Materials Discovery Facility (a 'Materials Discovery Toolbox') – a world-first research tool which introduces elements of automation and artificial intelligence to the field of materials discovery.

The main purpose of Materials Discovery Toolbox is to accelerate the development of novel, printable, photovoltaic materials such as lead halide perovskites and their lead-free analogues. This ground-breaking platform entails three integrated, robotic, modular glovebox sections. The first section synthesises chemical solutions and inks from liquid and solid chemical precursors and solvents. Essentially it is a fully automated 'lab bench' that carries out chemical reactions with high accuracy and reproducibility. The second section produces thin films from these inks via solution processing techniques like spin-coating. The third, and final, section hosts the necessary characterisation tools to determine the optical, electronic and structural properties of these films.

The glovebox-based modular chambers allow the creation of specialised environments for the reactions and techniques involved in the process such as the handling of moisture and oxygen-sensitive chemicals, intermediates and films.

Workflow across the toolbox is actively controlled in real time by integrated machine learning tools. Its AI-driven rapid optimisation of the series of activities allows for precise fabrication and testing of vast numbers of materials and structures while simultaneously cataloguing and 'learning' from the results of prior iterations.

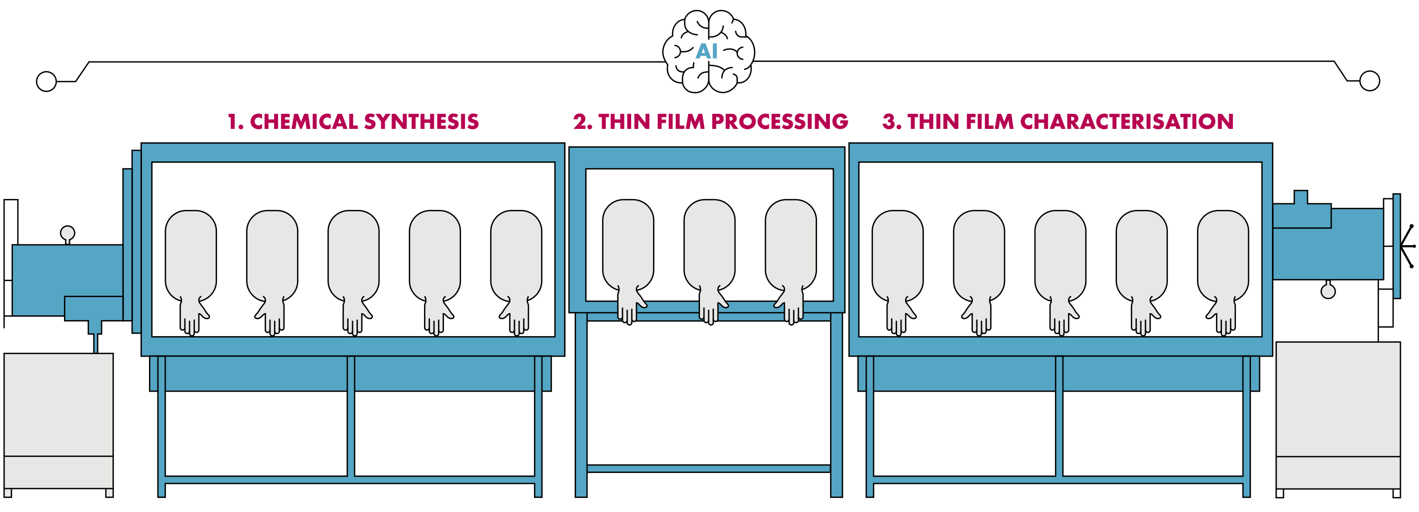
Construction of the High Throughput Solution-Processable Photovoltaic Materials Discovery Facility was made possible with a grant from the Australia Renewable Energy Agency (ARENA) and ACAP, with additional funding from Monash University, ANFF, and the ARC Centre of Excellence in Exciton Science.

The new research platform will be hosted at the Melbourne Centre for Nanofabrication (MCN) and managed jointly by ANFF and MCN. With a significant amount of its time available for use by ANFF clients, the Materials Discovery Toolbox facility will go online in 2023.

'ANFF is the best place to put complex and innovative tools so that they get the best chance to have an impact. ANFF enables a greater impact due to its open access nature and the supporting expertise,' ANFF CEO Jane Fitzpatrick said regarding ANFF's financial and logistical commitment to the Materials Discovery Toolbox. Since the fabrication of energy materials will involve additional processes that are not going to be contained within the glovebox, housing this facility within ANFF's national network will facilitate optimum coordination within the fabrication ecosystem.

The Materials Discovery Toolbox leverages physical processing with AI development to streamline the slow, laborious process of finding the right combination of material and structure to have the desired final photovoltaic device properties. When fully up and running, the platform will be able to fabricate and characterise one sample every 3-5 minutes, allowing the analysis of about 3,000 samples a week when operated 24/7.

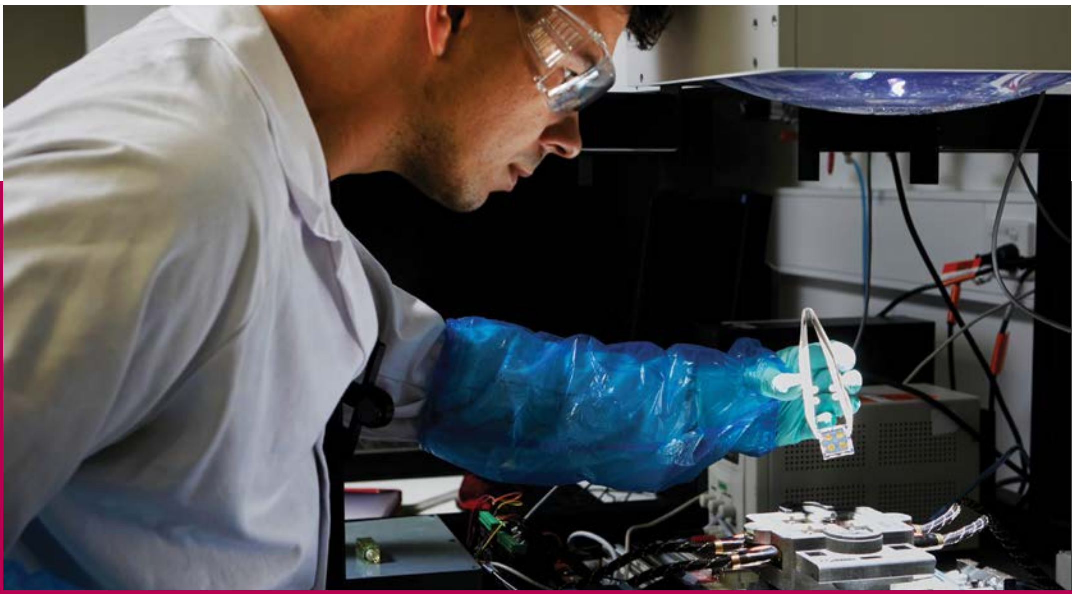
While this facility was designed primarily with solar technology in mind, the ANFF input from the earliest stages of design ensured that the platform can be adapted to support a wide variety of other users. The High Throughput Solution-Processable Photovoltaic Materials Discovery Facility is a unique system, and no comparable platform is currently available elsewhere in the world. By providing the ability to create better material systems in short time frames, the Australian research and industry community can leapfrog the competition and come to market with proprietary formulations with speeds that have not previously been available.



SCHEMATIC OF THE HIGH THROUGHPUT SOLUTION-PROCESSABLE PHOTOVOLTAIC MATERIALS DISCOVERY FACILITY.

PEROVSKITE, THE NEXT REVOLUTION IN THE SOLAR INDUSTRY

Access to world-class microfabrication technologies has enabled a team of Monash University researchers to develop an affordable and scalable production method for low temperature and high-performance perovskite solar cells.



DR ADAM SURMIAK INSPECTING A MICROFLUIDIC DEVICE FOR NiO THIN FILM PRODUCTION.

Exploiting the capabilities of a microfluidic device, Dr Adam Surmiak and Ms Monika Michalska and their collaborators from the Department of Chemical and Biological Engineering and the Department of Material Engineering at Monash University have created of one of the highest performing, low-temperature, perovskite solar cells (PSCs) in the world.

Perovskite is an ideal material for creating solar cells, as it is lightweight, cheaper to produce at scale and as efficient as today's leading photovoltaic material, silicon. Importantly, perovskite materials can be easily deposited from a solution onto the fabrication surface and even applied on flexible substrates while maintaining their high performance. For example, polyethylene teraphthalate (PET) is used as the plastic substrate for the solution-based deposition process that creates the perovskite thin film layer. PET is a transparent and low-cost polymer, but the material has a relatively low upper processing temperature limit (150°C). While perovskite thin films can easily be fabricated under these conditions, the other layers in a PSC are usually produced by high temperature processes that can melt plastics such as PET.

In a PSC, the light-absorbing perovskite is sandwiched between two thin films of charge-transporting material. These functional layers play an intrinsic role in the photovoltaic performance of a PSC, influencing its power conversion efficiency, long-term stability, and scalability. Dr Surmiak's microfluidic device enables fabricators to apply inexpensive techniques and simple approaches to depositing these additional PSC layers. His microfluidic strategy effectively eliminates the need for the high temperature process treatments used in traditional PSC recipes.

The mixing capabilities of the microfluidic device were used to facilitate nickel oxide (NiO) nanoparticle deposition. Thanks to this device developed by Dr Surmiak, the team could make a uniform, low-temperature NiO thin film layer, which functions as the hole-transporting layer (HTL) of a PSC.

The inspiration to integrate microfluidics into the fabrication of PSCs occurred to Dr Surmiak while attending ANFF-SA's Microengineering School. This annual program provides Australia's brightest engineering students with an insightful introduction to the design and fabrication of microfluidic/electronic, MEMS, optical and sensing chips with hands-on practical experiences in world-class cleanroom facilities.

The program sparked a productive collaboration, initially between Dr Surmiak and ANFF-SA, resulting in improved flow simulations and the development of his mixing device to optimise the NiO nanoparticle dispersion. As word spread of his team's success, other researchers across Monash University and the CSIRO approached Dr Surmiak, seeking permission to adopt his recipes and microfluidic mixers into their projects.

ANFF's ability to immediately understand what researchers are interested in and develop streamlined relationships for the fast delivery of projects has played an important role in Dr Surmiak's research success. 'The ANFF-SA team are open and honest professionals who have helped our team to recognise the bottlenecks and our process limitations,' said Dr Surmiak. 'We were able to learn from ANFF-SA's experience and employ those skills to further the development of our perovskite solar cells.'

The great range of tools and scientific support available through the ANFF network will hopefully help his team with future developments in reproducible, automated recipes for materials fabrication, which he hopes will lead to fully printed flexible PSCs, providing affordable, high-efficiency power conversion at scale.

COMMERCIALISING TECHNOLOGY FOR POWER SEMICONDUCTORS

Semefab, a UK based semiconductor manufacturer, will enter mass production of silicon-carbide Schottky diodes using a patented technology developed at the Queensland Micro- and Nanotechnology Centre at Griffith University.

Sales of electric cars doubled in 2021 to a new record of 6.6 million, according to Global Electric Vehicle Outlook. Even with the current strains in our global supply chains, electrical vehicle sales continue to skyrocket. Securing this future growth will demand investment into diversifying battery manufacturing and parts innovation.

There are over 15,000 components in an electric vehicle. To provide stable supplies of some of the critical parts, the semiconductor supply chain requires collaboration across thousands of suppliers and thousands of global kilometres and includes research and development (R&D), production, and distribution.

R&D underpins the supply chain as the source of innovation and technological advances in semiconductor component design, fabrication and testing.

Among those thousands of components is the diode, a semiconductor-based device that allows current to flow in only one direction through the material and acts as a one-way switch for current. Diodes are the most used semiconductor device in electronic circuits.

Common p-n junction diodes are based on an interface between two types of silicon (Si): p-type Si is connected to the positive terminal to form the anode (+ end), and n-type Si is connected to the negative terminal (- end), forming the cathode. Conventional current flows through the diode from the positive end to the negative end.

A Schottky diode is a different category of diode that consists of a junction between a metal and a n-type semiconductor, such as Si. The metal side acts as the anode, and the semiconductor acts as the cathode, meaning current can flow from the metal side to the semiconductor side, but not in the opposite direction. Schottky diodes exhibit faster switching between on/off states, which enables them to waste much less power compared to p-n junction diodes.

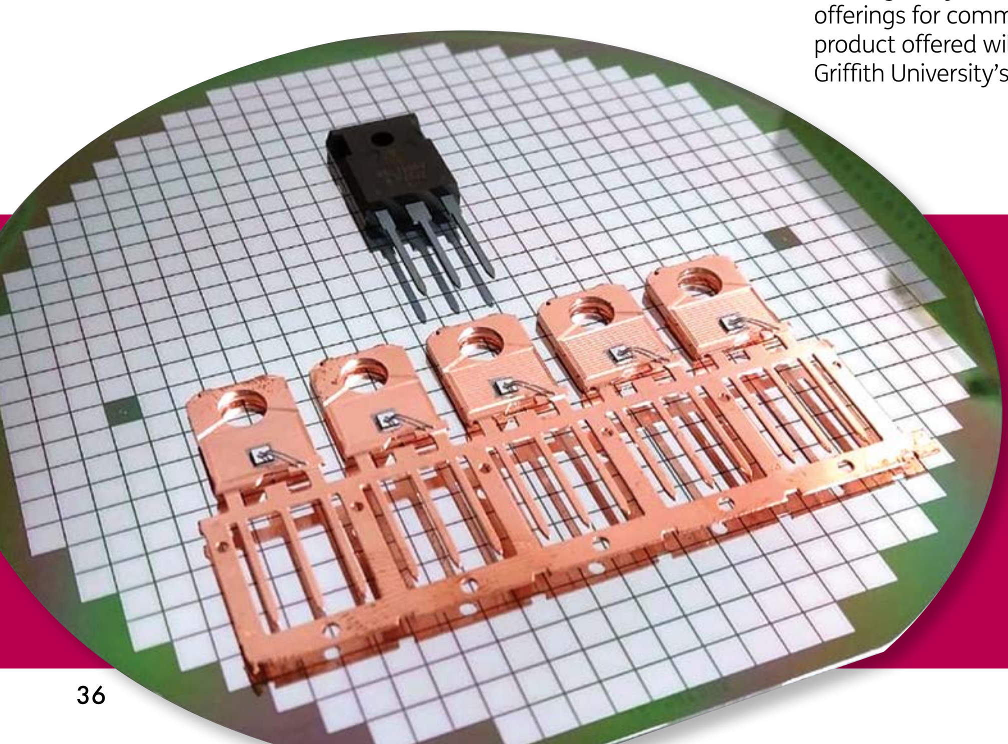
While Si-based Schottky diodes can offer significant advantages over their p-n junction counter parts, they cannot block current flow at high voltages. The ability for diodes to operate at high voltages is crucial for applications such as solar power inverters, electric motor drives, electric vehicle (EV) chargers, and uninterruptable power supplies.

This technical roadblock has been removed by changing the semiconductor material from Si to silicon carbide (SiC) – a semiconductor that can withstand ten times higher electric field (voltage) and has three times higher thermal conductivity (heat removal capability) than Si.

But every R&D innovation in a component comes with unwanted complications. Fabrication and production equipment is optimised for the existing technology. A switch to a new technology often requires expensive retooling of existing fabrication equipment or the introduction of a completely new process. With a smaller number of companies equipped for fabrication of the new device, the result is a destabilisation of the supply chain.

Researchers at Griffith University and ANFF-Q have developed and patented new SiC Schottky diode technology that features improved diode performance and can be manufactured by standard silicon-processing equipment. Because their SiC process re-design does not require retrofitting or new fabrication machines, their revolutionary technology reduces the fabrication cost and eliminates costly capital investment required by the existing design of SiC devices.

Attracted by the growing demand for more efficient and smaller energy-conversion systems, Semefab and Queensland Semiconductor Technologies Pty Ltd (Semefab's subsidiary) have partnered with Griffith University to transfer the SiC technology to Semefab's newly open fabrication line for power semiconductors. Starting this year, Semefab is expanding their power product offerings for commercial product manufacturing, and the first product offered will be the SiC Schottky diode produced with Griffith University's patented method.



GRIFFITH UNIVERSITY'S SiC SCHOTTKY DIODES IN VARIOUS STAGES OF MANUFACTURE. EACH ALUMINIUM SQUARE ON THE SiC WAFER IS AN INDIVIDUAL DIODE.

SOLID-STATE COMPUTING THAT MIMICS THE HUMAN BRAIN

Brain-inspired computing mimics brain structure and function to create energy-efficient computers that can think creatively, learn from experience and evolve to recognise things they've never seen.

There is increasing demand for computers that match the human brain's ability to adapt to novel situations and 'learn' from unstructured input data like images, audio, video and text files. Neuromorphic computing aims to achieve this by emulating the architecture of the human brain.

In a conventional digital computer, the central processing unit (CPU) directs the different parts of a computer to carry out program instructions in a sequential manner. It must complete one task at a time, with the current task completed before executing the next in the queue. Modern CPUs can run more than one thread of execution concurrently, multitasking among multiple threads or programs.

On top of that, CPUs do not contain the actual data or instructions for processing tasks. Instead, this information is stored in memory, requiring constant back and forth exchange between the CPU and memory components.

In contrast, our brain is a living computer with tremendous computational power and energy efficiency. First, it has massive, innate parallel processing ability. Different regions of the brain are interconnected and interact directly with each other, so our brains can perceive and process many different types of information all at once.

Second, neurons communicate with each other through cell-to-cell connections called synapses, and synapse formation creates memory and learning within the brain. Our brain contains over a quadrillion synaptic connections, and each neuron may be passing signals to up to 10,000 other neurons. Memory is embedded into the processing system, and information is distributed throughout the neural network rather than being shuffled back and forth between distinct components.

Using our amazing brains as inspiration, neuromorphic computing re-envisions the design of computer hardware to mimic the processes of biological computation. Emeritus Prof. Rob Elliman's research group in The Australian National University Research School of Physics is developing solid-state synapses and neurons for this purpose.

In one aspect of this work, Dr Sanjoy Nandi and Mr Sujan Das are developing nanoscale oscillators as neurons. Oscillators periodically fluctuate between two states based on changes in energy. Their artificial neurons have a simple metal-oxide-metal layered structure based on a specific phase of vanadium oxide (V_3O_5) with an electrical conductivity that increases abruptly at a temperature of ~147°C. Passing current through the nanoscale neuron warms the V_3O_5 through resistive heating, just like the wires in a toaster. The device's resistance changes accordingly, and in an appropriate circuit, can oscillate between high and low resistance states.

To fabricate a neural network, these nanoscale oscillators are coupled together to form a massively parallel array, with information encoded in the relative phases of the oscillators and learning implemented by tuning the strength of the coupling elements. Such architectures replicate the parallel processing and memory embedding found in biological neural systems.

It is expected that oscillating neural networks (ONNs) will provide an energy-efficient means of undertaking simple repetitive functions, such as recognising or matching patterns, and will facilitate developments in areas such as medical image analysis, facial recognition and authentication, voice recognition and language translation, and cyber security.

The Elliman group's development of devices and simple networks has relied heavily on access to ANFF-ACT fabrication facilities and expertise. If successful, their neuromorphic research will advance the understanding and application of brain-inspired computing and help Australia to develop a leading edge in the rapidly emerging field of neuromorphic computing devices.

CREATING IMAGES OUT OF THIN AIR

The Australian National University researcher Dr Tuomas Haggren's light-emitting metasurface goes beyond the limits of normal materials to manipulate how nanoscale patterns affect the properties of light.

From Princess Leia of Star Wars begging for Obi-Wan Kenobi's help to the holodeck adventures in Star Trek, depictions of holograms have evolved from 3D images that we can see to 3D spaces with which we can interact. More recently, 'holograms' have allowed us to resurrect dead celebrities who can perform and interact with audiences. Holograms seem to be infiltrating our daily lives.

While the previous examples describe wonderful visual effects, they aren't actually holograms but rather sophisticated optical illusions based on the projection and reflection of light from glass, mirrors and other surfaces. Likewise, spinning LED images, 3D displays, VR and AR are hologram-like but not the real deal.

A true hologram is a realistic 3D object that appears in space just like a real object but is made of nothing more than light. Bringing holograms out of science fiction into our daily lives is the goal of Dr Tuomas Haggren, a postdoctoral researcher at The Australian National University's Department of Electronic Materials Engineering and the ARC Centre of Excellence for Transformative Meta-optical Systems (TMOS).

In the not-so-distant past, our attempts to manipulate light were constrained by the limited number and types of material available in nature. For example, eyeglasses bend transmitted light to a focused location on the retina. Our ability to correct vision for near- or far-sightedness or astigmatism is limited to changing the shape and thickness of the lens. Nature itself is the limiting factor in our attempts to create 3D objects in thin air because we are stuck with the properties inherent to the material we use.

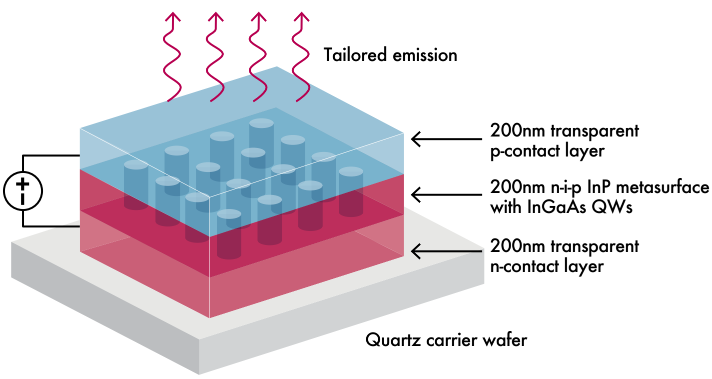
A new paradigm in manipulating light is to go beyond the material limitations of a substance by manipulating how surfaces affect the reflection, transmission, and bending of light. These quasi-2D thin film 'meta' surfaces have nanoscale patterns and structures that interact with light and energy in ways not found in nature. Metasurfaces operate by altering the way in which light bends and behaves as it passes through the nanoscale obstacles and openings. These nanoscale patterns provide the ability to precisely control the light path and properties beyond what is possible by natural materials.

With fabrication processes made possible by ANFF-ACT, Dr Haggren is developing an electrically injected, light-emitting metasurface device. His device is based on an indium phosphide (InP) metasurface film sandwiched between two transparent charge-carrying layers. InP is a semiconductor that emits photons of light when injected with an electrical current. The InP is studded with InGaAs quantum structures that confine charge carriers to tailor the colour of the emitted light. Rather than diffusely glowing like a LED, the light-emitting metasurface produces a coherent nanolaser beam in which the released wavelengths are in exact alignment in space and time.

Engineered metamaterials and coherent beams enable much stronger tunability and reconfigurability than any natural, non-structured material. Haggren's metasurface nanolaser is a promising candidate for future flat devices that can change various properties of emitted light such as colour, brightness, phase, polarisation and direction.

Arrays of nanoscale emitters can be directed toward the same focal point in space, what would emerge at that location is a 3D object composed solely of light – a true hologram.

Advances in nanoscale emitters will improve various technologies including virtual reality with improved simulated environments for training and education to next generation wireless optical networking technology (called Li-Fi) for ultra-high speed data transmission.



SCHEMATIC OF A LIGHT-EMITTING InP METASURFACE DEVICE.

ACCESSING ANFF

ACCESS STEPS

ANFF is committed to exceeding the customer service expectations of our clients.

CONTACT US AT INFO@ANFF.ORG.AU → DISCUSS PROJECT WITH ANFF AND ESTABLISH PATHWAY → ACHIEVE PROJECT OBJECTIVE

RESEARCHERS

For researchers seeking to engage with ANFF, we invite you to contact your local node who can have an initial discussion around how ANFF capabilities and expertise can align with your research needs.

INDUSTRY

ANFF's Client Engagement Facilitator (CEF) team, are the primary contact for any industry client whose needs transcend a single ANFF node, or for those that require assistance finding the best way that ANFF can support a project. The CEF then acts as a concierge, taking ownership of the client's problem and then engaging the ANFF network to find the best possible solution.

ANFF-C

A new platform, ANFF-C, has been created to support ANFF clients to move IP generated at ANFF facilities into the real world. Dr John Morrison, the Director of ANFF-C, would be delighted to discuss with you how the platform can be of assistance.

ACT Node
Facility Manager: Dr Horst Punzmann
E: horst.punzmann@anu.edu.au
https://anff-act.anu.edu.au

Materials Node
Facility Manager: A/Prof Stephen Beirne
E: sbeirne@uow.edu.au
www.anffmaterials.org

NSW Node
Facility Manager: Matthew Boreland
E: m.boreland@unsw.edu.au
www.anff-nsw.org

OptoFab
Facility Manager: Dr Benjamin Johnston
E: benjamin.johnston@mq.edu.au
www.optofab.org.au

Queensland Node
Facility Manager: Anthony Christian
E: a.christian@uq.edu.au
www.anff-q.org.au

SA Node
Facility Manager: Simon Doe
E: simon.doe@unisa.edu.au
www.anff-sa.com

Victorian Node
General Manager: Dr Sean Langelier
E: sean.langelier@nanomelbourne.com
www.nanomelbourne.com

Western Australia Node
Facility Manager: Prof. Mariusz Martyniuk
E: mariusz.martyniuk@uwa.edu.au
www.mrg.uwa.edu.au

VISIT ANFF.ORG.AU TO FIND OUT MORE

ANFF.ORG.AU