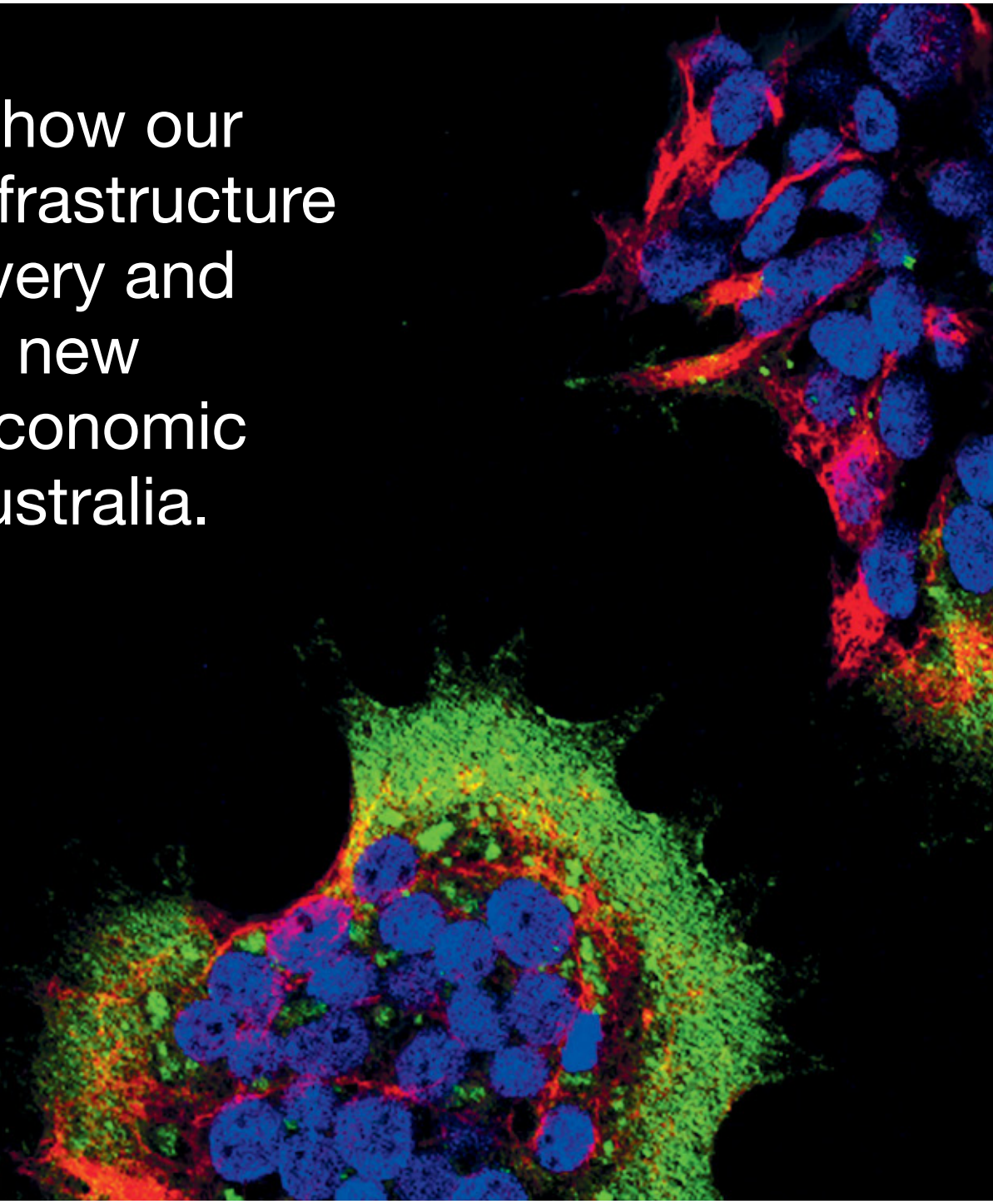
ammrf
Australian Microscopy
& Microanalysis Research Facility

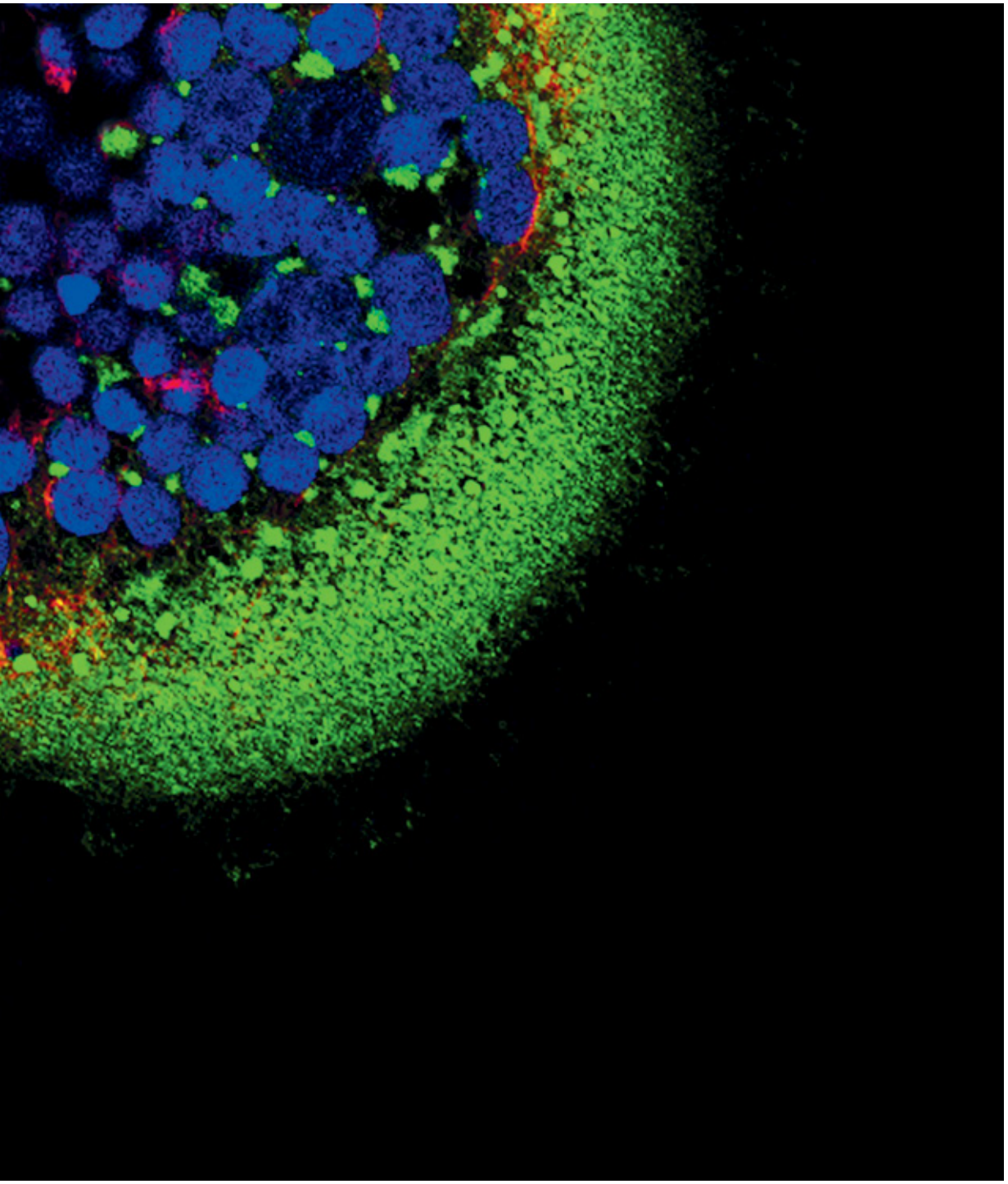
PROFILE 2017

We invite you to explore how our collaborative research infrastructure opens the door to discovery and innovation. See how this new knowledge can deliver economic and health benefits to Australia.

Image: Confocal image of kidney cells infected with Nelson Bay virus (green). AAHL Biosecurity Microscopy Facility, CSIRO

Cover image: Collagen in lung tissue revealed by second harmonic generation multiphoton imaging. Gavin Tjin, University of Sydney





CONTENTS

Half of this profile showcases the work & achievements of the researchers. Congratulations to them all.

Note: If you're a page flicker, don't miss this section. It's the good stuff.

NEWS FROM THE TEAM

MINISTER

Senator the Hon. Simon Birmingham,
Minister for Education and Training

The continuing development of research infrastructure in Australia is vital in supporting the important partnerships between business and our best and brightest researchers.

The Turnbull Government is committed to working with industry, business and the research sector to continue to deliver world-class facilities that allow Australian researchers to solve complex problems and make new discoveries.

The Australian Microscopy and Microanalysis Research Facility (AMMRF) has continued its excellent work in supporting leading edge research across a wide variety of fields, including work in improving the understanding of molecules in cancer and diabetes.

I wish the AMMRF every success in the years ahead in the important work they undertake.

CHAIR

Dr Gregory R. Smith
Chair of Board

The AMMRF operates across multiple Australian University nodes. Each node is primarily invested in different microscopy instrumentation, expertise and technologies. Thus, this collaborative model optimises capital utilisation and the productivity of microscopy research capabilities.

During 2017, the AMMRF responded to the Federal Government's Roadmapping program for the next phase of national research infrastructure. This timely opportunity to recommend a next phase of capital investment in microscopy supports the ability of Australian research to retain its competitive innovation and research position into the future. Nonetheless, during this roadmap submission phase, the AMMRF has also continued to improve its core services delivery, further build on its international connections, and increase its Australian industry engagement.

The AMMRF board has keenly supported the formation of a partnership between the organisation and MTPConnect; the Medtech/Pharma Industry Growth Centre. This new initiative offers vouchers that allow those in early stage medtech ventures to access microscopy and microanalysis infrastructure at more affordable, subsidised rates. This new capability is expected to enable speedier access to more informed research and innovation outcomes in the sector. Replication of similar capabilities in other Australian industry sectors remains a future AMMRF target.

CEO

Prof. Julie Cairney
Chief Executive Officer

In 2017 we celebrate ten years of the AMMRF. We are proud to have achieved a culture in which many of Australia's major research institutions find it natural to view microscopy infrastructure as tools for national collaboration, and are comfortable offering open access to all Australian researchers, via the AMMRF. This was not always the case!

It's been an exciting year. We've supported over 3000 researchers and some of their incredible stories are featured in this profile, starting on p22. I particularly loved hearing about the UNSW work on solar battery technology that might lead to solar charging of smart phones (p28), and the work Reece Limited have been doing in WA to develop a new class of antibiotic that can kill superbugs (p41).

We're thrilled to be establishing a new partnership with MTPConnect – the Medtech and Pharma Growth Centre, to create vouchers that will allow the medtech industries, especially start-ups and small businesses, to access our world-class microscopy infrastructure at affordable rates.

We're also looking forward to partnering with the Australian National Fabrication Facility for our joint ANFF/AMMRF Showcase – 'Make and Measure'. This will allow us to highlight how our facilities enable innovative research in fields including medical technologies, advanced manufacturing, energy and agribusiness.

As our users know, the size and complexity of the data we acquire is now posing new challenges for data storage, transfer and analysis, and we have dedicated significant effort this year to working on a national strategy for data handling. We're looking forward to partnering with the new National Research Data Cloud to support this plan, allowing us to continue to enable world-leading research.

STATS IT'S BEEN A BUSY YEAR:

We enable discovery and innovation across many scientific disciplines and industries. Our facility complements other national research infrastructure, bringing economic, health and technological benefits to Australia. We support high-impact research:

16,000+ PUBLICATIONS SINCE 2007

200 INSTRUMENTS

225,000 HRS BEAMTIME

120 STAFF

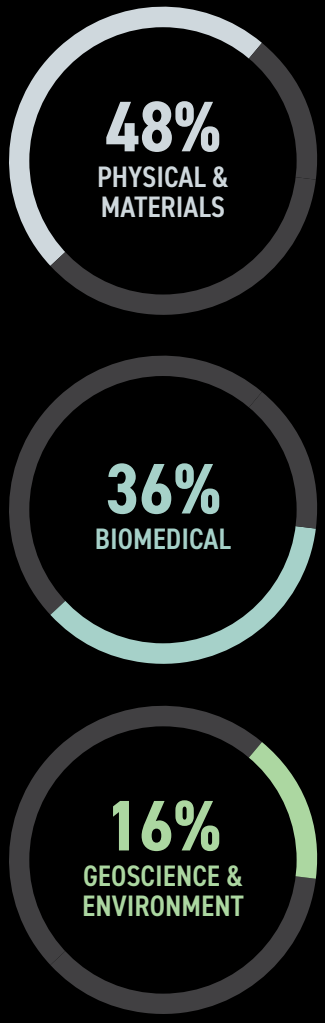
111,000+ ONLINE RESOURCE USERS

SUPPORTING DIVERSE INDUSTRIES

70+ INDUSTRY CLIENTS

3,100+ USERS

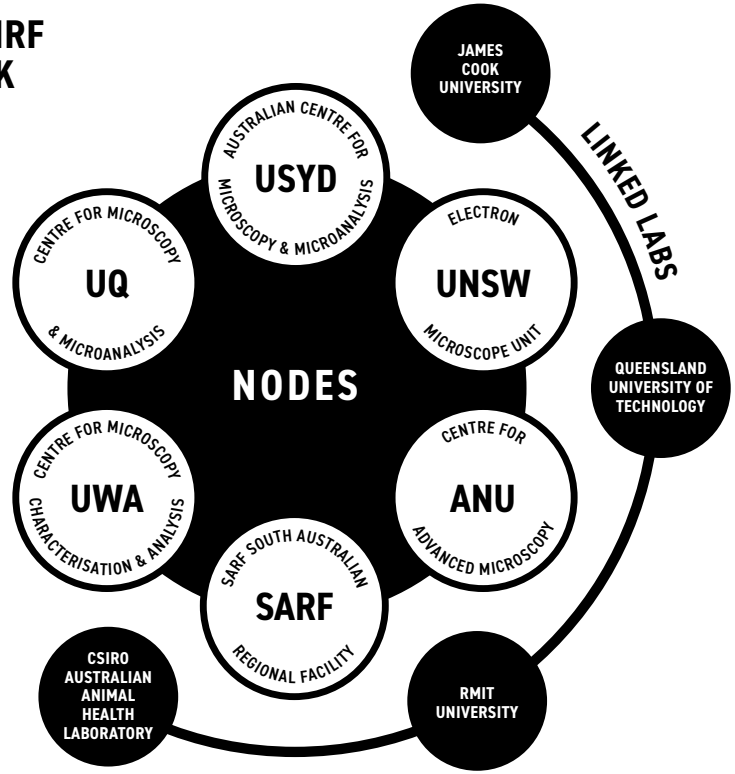
RESEARCH COMMUNITY



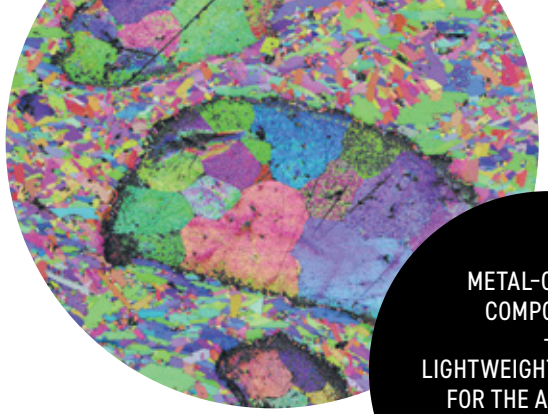
EST. 2007

Established in 2007 the Australian Microscopy & Microanalysis Research Facility (AMMRF) is a national grid of instruments, expertise and online tools dedicated to nanostructural characterisation. Medical, soft matter, plant, materials and geological sciences all require cutting edge microscopy in order to address Australia's Strategic Research Priorities.

THE AMMRF NETWORK



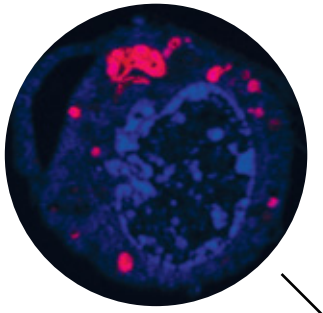
SOLAR PHONE



METAL-CERAMIC COMPOSITES – LIGHTWEIGHT MATERIALS FOR THE AEROSPACE AND TRANSPORT INDUSTRIES

PHYSICAL

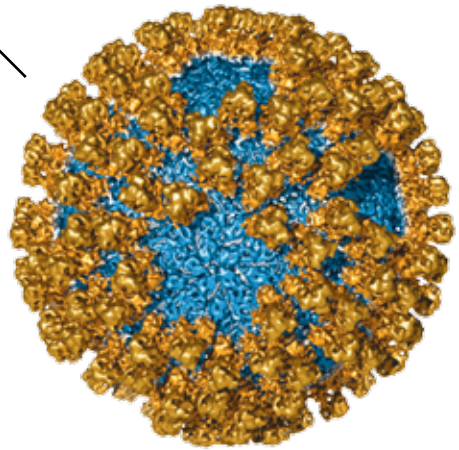
SYNTHESISING NEW NANOMATERIALS FROM LIQUID METALS



SUBCELLULAR DRUG TRACKING

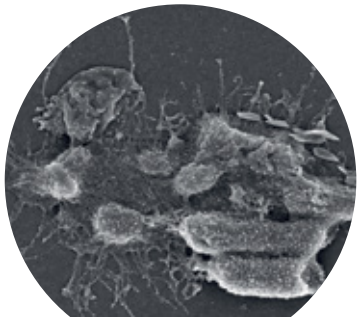
OVER 3,000 RES

VIRUS-LIKE NANOPARTICLES FOR TARGETED DRUG DELIVERY



EMPOWERING INDUSTRY

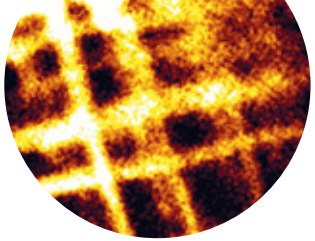
NEW WEAPON AGAINST SUPERBUGS



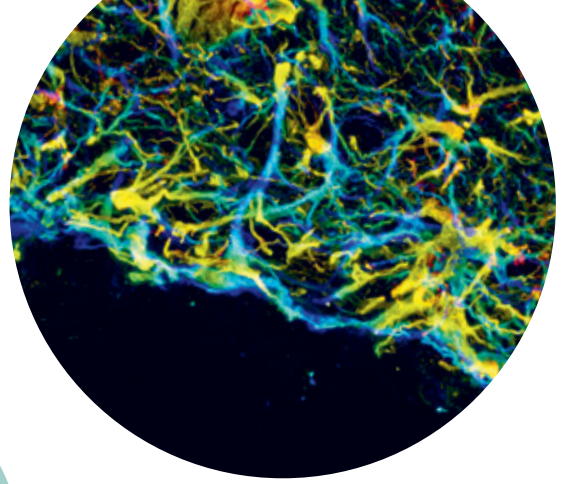
PROTECTING OUR NATIONAL POULTRY INDUSTRY – WORTH OVER $5.6 BILLION P.A.

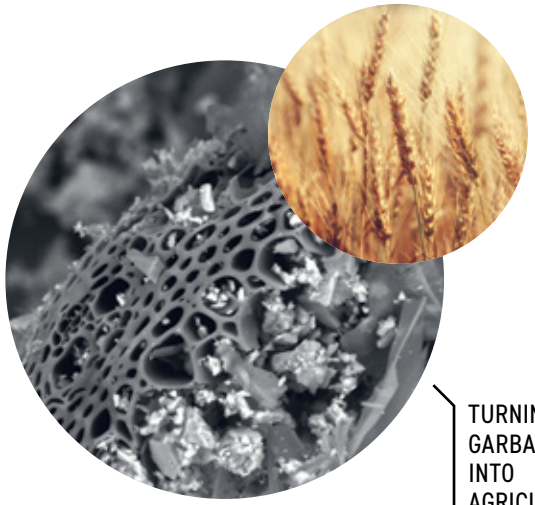
BIOCHAR – INCREASE CROP YIELDS BY 31%

ENVIRONMENTAL



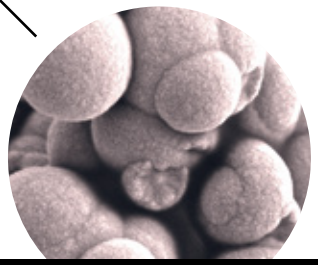
ENABLING
T-CELL THERAPIES





TURNING
GARBAGE
INTO
AGRICULTURAL
BOOSTER

ULTRA-HIGH RESOLUTION
ANALYSIS OF BIOMARKER VESICLES



BIOMEDICAL

BIOMATERIALS
FOR BRAIN REPAIR

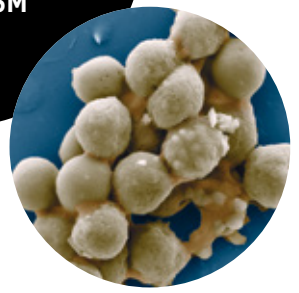
EARCHERS P.A.

EMPOWERING RESEARCH FOR SOCIAL IMPACT & ECONOMIC PROSPERITY

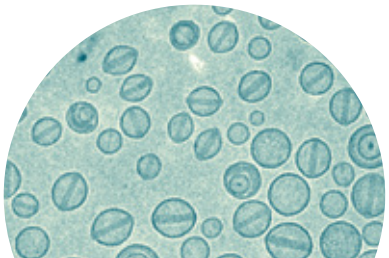
See pages 22 - 43 for a selection of our research stories.

TECHNOLOGY

SAVING LIVES
–
DISCOVERY OF
NEW CLOTTING
MECHANISM



SUPPORTING SMES –
VISUALISING LIPOSOMES

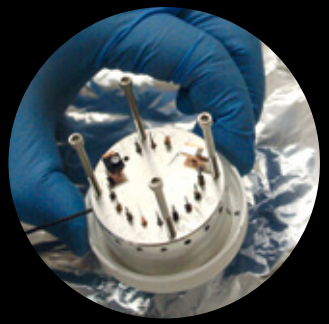


EQUIPMENT & EXPERTISE

TAKE A CLO

We enable access to microscopy and microanalysis for all Australian researchers on the basis of merit.

Our federally funded collaboration has enabled strategic investment in flagship instruments, many of which are unique in Australia. They are run by dedicated experts, to help researchers get great results. The AMMRF offers industry and academia a wide range of specialised techniques, outlined on this page. Collaborative strategic investment in open access facilities maximises Australian research efficiency and productivity.



SPECIMEN PREPARATION

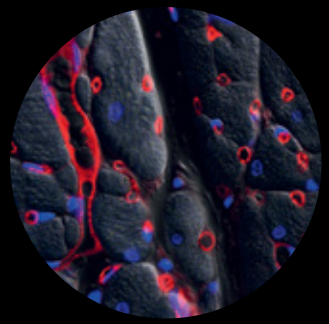
Biological & Materials

Cell Culturing & Molecular Preparation

Thermomechanical Processing

Ion Milling & Machining

Ion Implantation



LIGHT & LASER OPTICS

Confocal, Fluorescence & Optical Microscopy

Flow Cytometry & Cell Sorting

Live-cell Imaging

Vibrational & Laser Spectroscopy

Laser Microdissection

SCANNING ELECTRON MICROSCOPY

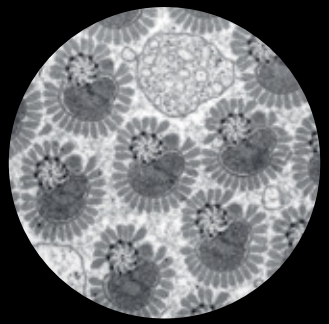
Imaging & Analytical Spectroscopy

In-situ Imaging & Testing

Cathodoluminescence

Electron Backscatter Diffraction

OSER LOOK



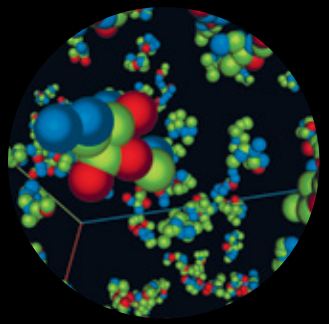
TRANSMISSION ELECTRON MICROSCOPY

Imaging & Analytical Spectroscopy

Cryo-techniques & Tomography

Phase & Z-contrast Imaging

Electron Diffraction



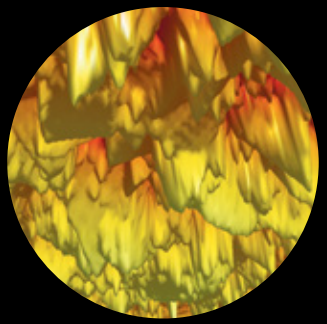
ION & SPECTROSCOPY PLATFORMS

Secondary Ion Mass Spectroscopy

Imaging Mass Spectroscopy

Atom Probe

LA-ICP-MS

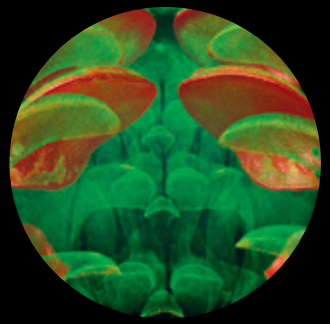


SCANNED PROBE TECHNIQUES

Atomic Force Microscopy

Scanning Tunneling Microscopy

Near-field Scanning Optical Microscopy

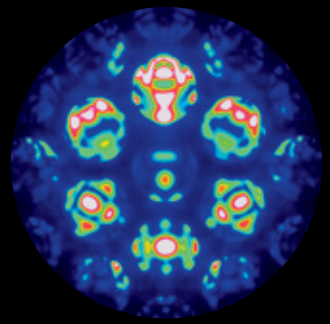


X-RAY TECHNOLOGIES

X-ray Diffraction

X-ray Fluorescence

X-ray Micro & Nanotomography



VISUALISATION & SIMULATION

Computed Spectroscopy

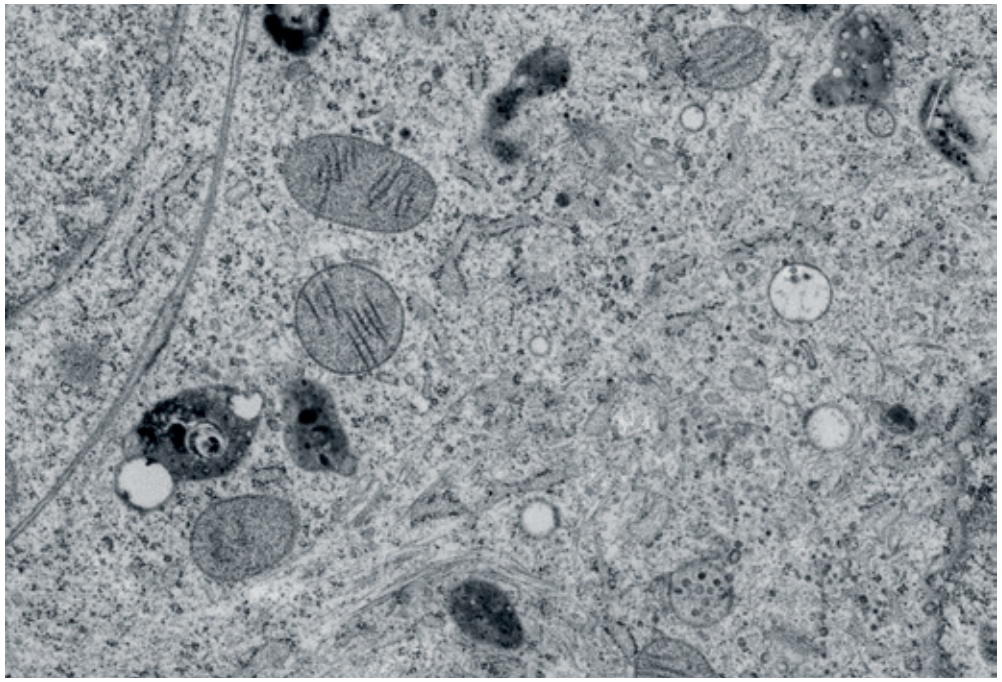
Computed Diffraction

Image Simulation & Analysis

Data Mining

TECHNIQUE DEVELOPMENT

AMMRF resource scientists are researchers in their own right. As well as helping us get the best from our instruments they have also developed techniques and new instruments that have an impact on science and the economy around the world.



THREE HOUR FREEZE SUBSTITUTION

EXCELLENT SAMPLES – GREATER EFFICIENCY

Sample preparation is critical to good microscopy. Previous preparation methods of biological samples for electron microscopy could take several days. A much faster method developed in the AMMRF yields as good or better results in just three hours or less.

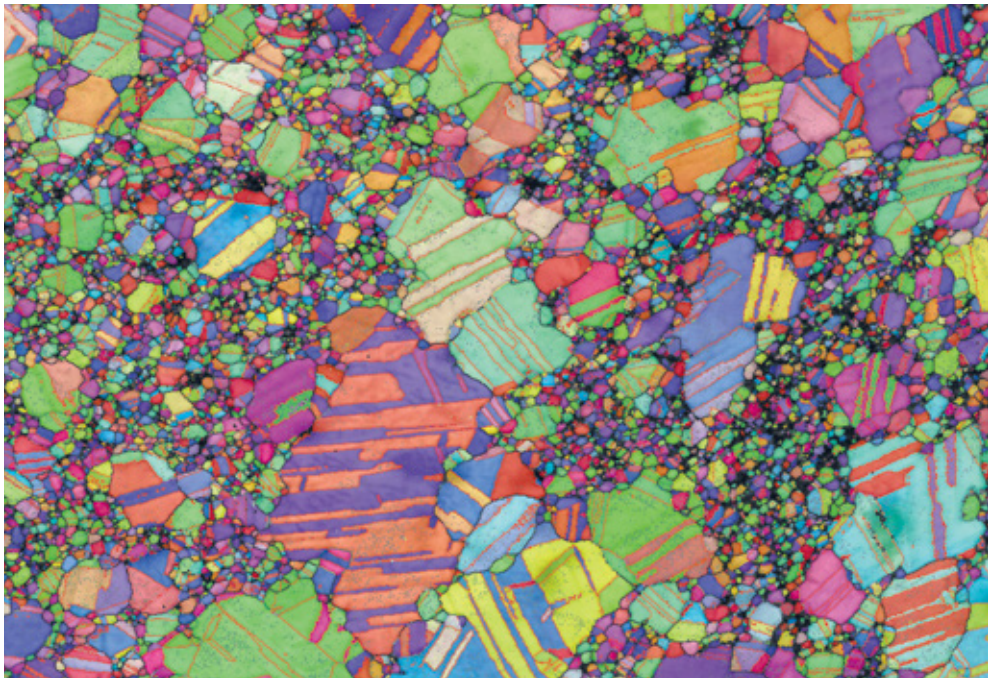
This method was published in the *Journal of Microscopy* in 2011 and currently has 96 citations with authors from 22 countries.

This method is now being further developed to prepare larger sample blocks for serial block-face scanning electron microscopy – a highly demanding technique, dependent on excellent sample preparation. This has reduced the time required from five days to one. These time savings markedly improve efficiency.

Invitations to present this work at:

- From 3D Light to 3D Electron Microscopy Workshop, Heidelberg, Germany.
- Microscience Microscopy Congress 2017, Manchester, UK
- EMBO Course on Volume Electron Microscopy by Automated Serial SEM, Basel, Switzerland

Developed by: Dr Rick Webb
AMMRF TEM expert | University of Queensland
in collaboration with Dr Kent McDonald
University of California, Berkeley



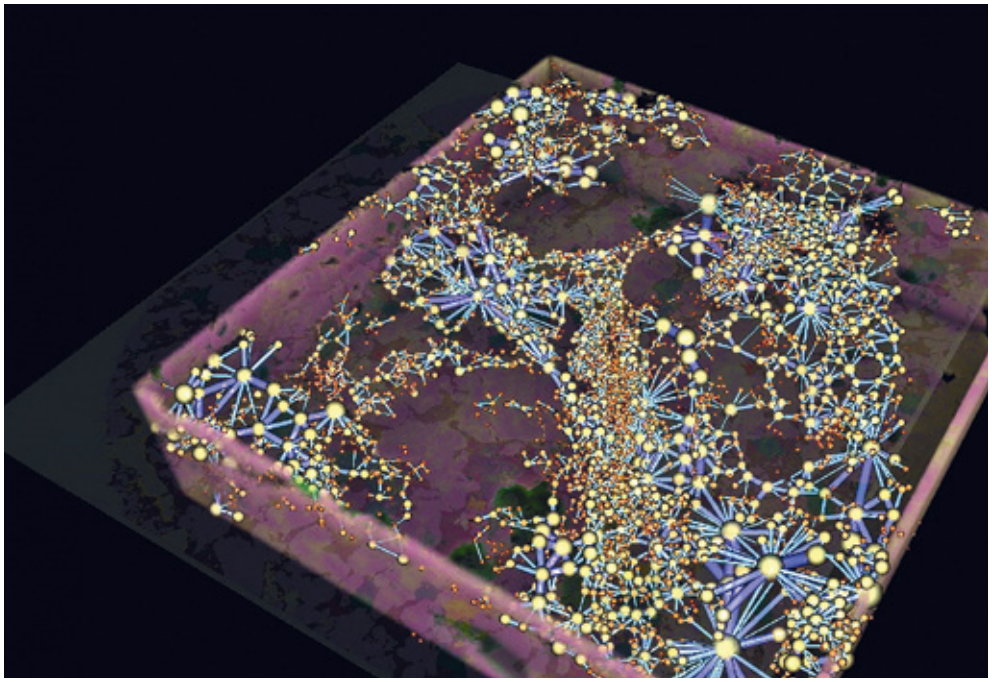
TRANSMISSION KIKUCHI DIFFRACTION IN THE SEM
SUPPORTING THE REVOLUTION IN NANOSTRUCTURED MATERIALS

ACHIEVING 10 X MORE DETAIL

Enables at least ten times more detailed analysis of the crystal structure of materials at the nanoscale.

- This method was published in *Ultramicroscopy* in 2012.
- 193 citations with authors from 29 countries
- this is increasing year on year.

Developed by: Dr Pat Trimby
AMMRF SEM expert | University of Sydney



HELICAL X-RAY MICROTOMOGRAPHY
PROVIDING POROSITY SERVICES TO THE OIL AND GAS INDUSTRY

Prof. Tim Senden, a staff member in the AMMRF node at the Australian National University and colleagues developed a helical X-ray microtomography instrument. This was patented in 2010.

2009

Spin-off company Digitalcore formed to use this instrument and associated software solutions to provide porosity services to the oil and gas industry

2013

Digitalcore merged with Norway's Numerical Rocks to form Lithicon

2014

LITHICON WAS SOLD TO FEI (NOW A THERMO-FISHER COMPANY) FOR $76 MILLION

FEI markets the Heliscan microCT and it forms the basis of one of their two core integrated Industry Workflows that take customers from problem identification through sample preparation, imaging and analysis to a solution.

Developed by: Prof. Tim Senden and colleagues
AMMRF | Australian National University

YOU CAN SEE ATOMS – MORE CLEARLY THAN EVER

We continue to update our microscopy infrastructure to provide sophisticated tools so Australian research can remain at the forefront in these areas. Strategic placement of these instruments within the AMMRF will maximise the impact for Australia.

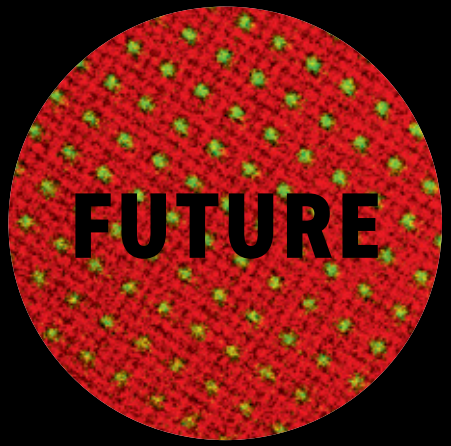
Constant advances in microscopes and detectors enable researchers to see deeper into the atomic world and help to answer fundamental scientific questions.

Atoms are the basic building blocks of life and all materials. Visualising matter at this scale reveals the structures that determine properties and behaviour at larger scales. Across all fields of research, we regularly want to engineer materials or manipulate structures at the atomic length scale, which is why we need to see atoms clearly.

To do this we also need to see the spaces between the atoms – spaces of just one tenth of a nanometre. This has recently become possible with the development of increasingly powerful transmission electron microscopes (TEMs).

The next step has been to identify elements at the atomic scale and the very latest instruments can make movies to watch atoms move around as experimental conditions change.

The three images on the right show how technology has advanced over the last 12 years. These are all images of atoms in crystal lattices and reflect the increasing resolution and elemental analysis capability.



CRYSTALLINE MATERIALS

ACQUIRED – 2005

Stacks of atoms are visible as lumpy black lines in this image. The spaces between the atoms are not clearly distinguishable.

ACQUIRED – 2014

Stacks of atoms are clearly visible in this TEM image of a new mineral.

2017 >

Atomic-resolution elemental analysis. The latest TEMs have high-speed movie capability capturing 15 of these images every second to visualise atoms moving around as experimental conditions are changed inside the microscope.

BIOLOGICAL MOLECULES

The AMMRF plans to expand and update its cryo-TEM capability to ensure that Australian researchers have access to this critical technology.

Understanding the structure of biological molecules is essential to understanding life - an enormous variety of proteins keep us working properly. These proteins are intricately folded and extremely structurally complex.

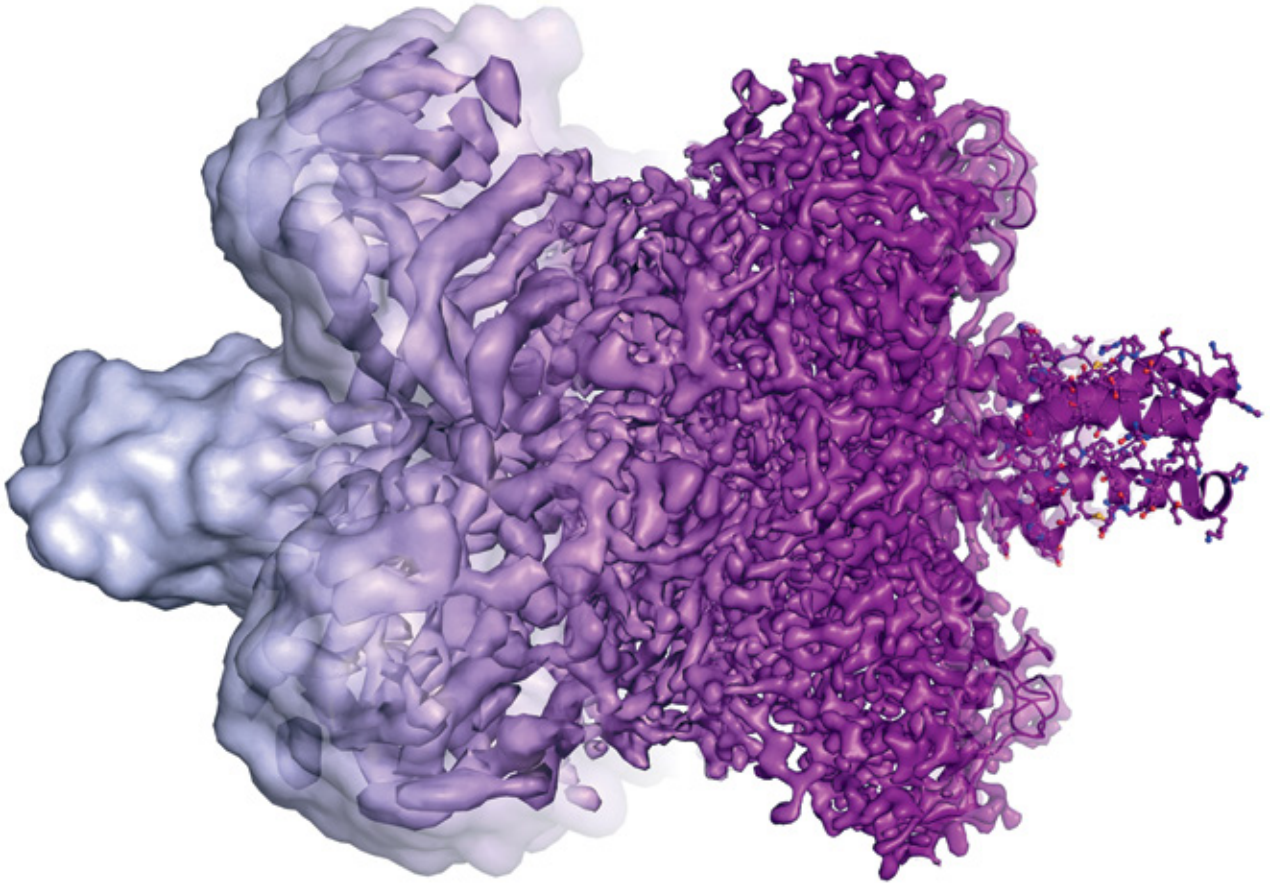
They are often organised into multi-molecular complexes and molecular machines. Capturing their structures in their functional states is crucial to matching structure with function. Preserving proteins with chemical fixatives can destroy this natural structure but snap freezing accurately preserves it. This is the key feature of cryo electron microscopy.

Due to recent technological innovations, cryo-TEM can now determine these biological structures at near atomic scale – a huge improvement on earlier instruments. This is illustrated on the right and enables more refined drug design.

2017 NOBEL PRIZE FOR CHEMISTRY –
CRYO-ELECTRON MICROSCOPY

Congratulations Jacques Dubochet, Joachim Frank and Richard Henderson
©® The Nobel Foundation

CRYO-EM DEVELOPMENT



RESOLUTION - PRE 2013 → **AT PRESENT**

Illustration of protein structure slightly adapted from:
© Martin Högbom The Royal Swedish Academy of Sciences

COMMERCIAL DEVELOPMENT

Microscopy in the AMMRF has been critical in allowing researchers and new companies to capture the information they need to develop their products and move along the commercialisation pipeline.

THEN

HAZER

FOUNDED 2010
SPIN OFF – UWA

Microscopy was essential for development of the Hazer process, which uses natural gas and unprocessed iron ore to create low-cost, low-emission "clean" hydrogen, a key fuel in the transition to low carbon economy. In addition to the hydrogen product, Hazer produces synthetic graphite used in lithium ion batteries to power electric vehicles.

2015
LISTED ON ASX - RAISED $5 MILLION

GELION

UNDERLYING RESEARCH
BATTERY INTEGRATED HOUSES

"The idea is to build houses with batteries inherently included as part of their structure, ready to take advantage of rapidly improving, solar energy technology and also to serve as a buffer for the grid, enabling an ever greater share of renewables to be connected, while grid stability is maintained" Prof. Thomas Maschmeyer.

The nano-structured gels are claimed to have better performance than lithium ion batteries in their charging and discharging speed, as well as being smaller, safer, more durable and cheaper. Development of the Gelion technology depended on scanning electron microscopy in the AMMRF.

TRIMPH

FOUNDED 2015
SPIN OFF – UNIVERSITY OF SYDNEY

Featured in the 2016 Profile, Trimph spun off from the University of Sydney in 2015 on the back of four patents exclusively licensed from the University. Trimph produces sterile medical devices in the ISO Class 5 isolator, a custom-built freeze dryer attachment, allowing operators to maintain the integrity of the aseptic product in a state of the art clean room in Sydney.

DEC 2016
ATTRACTED $2.5 MILLION IN GRANTS & INVESTMENT

NOW

MARCH 2017
PRE-PILOT PLANT COMPLETE

APRIL 2017
FIRST HYDROGEN & GRAPHITE PRODUCED

OCTOBER 2017
MARKET CAP. OF AROUND $34 MILLION

Hazer Group joined forces with its biggest shareholder Mineral Resources to develop a plant to produce synthetic graphite for lithium batteries. This plant will initially be targeted towards the production of at least 1,000 tonnes per annum (tpa) of ultra-high purity graphite and capable of modular expansion to a nominal 10,000tpa. The deal allows Hazer to continue pursuing global hydrogen production opportunities.

MAY 2015
GELION FOUNDED

Prof. Maschmeyer set up University of Sydney spin-off company Gelion Pty Ltd – attracted attention from investors and strategic partners in the United States, Germany and Israel.

APRIL 2016
$11 MILLION COMMERCIAL PROTOTYPE

Renewables company, Armstrong Energy, paid $11 million for a commercial prototype of a house that will have walls containing batteries invented by Maschmeyer.

Steven McCann Lend Lease CEO is also interested in this technology saying, "We're thinking about things like working with Professor Maschmeyer to use prefabricated wall segments, for example, as, effectively, battery storage or power storage facilities."

MARCH 2017
INCREASED THE TOTAL INVESTMENT TO $4.2 MILLION

Trimph secured government funding from the Accelerating Commercialisation Program, total of $1.4 million ($0.7 matched) – this increased the total investment to $4.2 million since Trimph's incorporation in August 2015.

APRIL 2017
FIRST HUMAN TRIAL STARTED

Outstanding progress for a Class III medical device company within 18 months of incorporation. TrimphDent is used for socket preservation; seven patients have been treated with TrimphDent, and healing progressed as expected.

OCTOBER 2017
SECOND CLINICAL TRIAL INITIATED

TrimphDent will be used in jaw surgeries with the first patient to be recruited in late 2017.

COLLABORATION

AUSTRALIA

AMMRF – Reaching out to support Australian research sectors

SUPPORTING CRSs

At least 16 new research projects from CRCs have started using AMMRF facilities in the last year.

MTPConnect

We are connecting with Industry Growth Centres to drive innovation in Australian industry. In particular we are partnering with MTPConnect to deliver the AMMRF Technical Voucher Fund. This delivers subsidised funding for medtech companies to access the microscopy they need to overcome hurdles in their commercialisation pathways.

CENTRES OF EXCELLENCE

We support research in 10 Centres of Excellence

UWA – NIKON CENTRE OF EXCELLENCE

Our UWA node has become a Nikon Centre of Excellence in Optical Microscopy – the only one in Australia and one of only 22 in the world.

FLAGSHIP INSTRUMENTS – EXTERNAL ACCESS

30% time on flagship instruments was for people based outside the host institution.

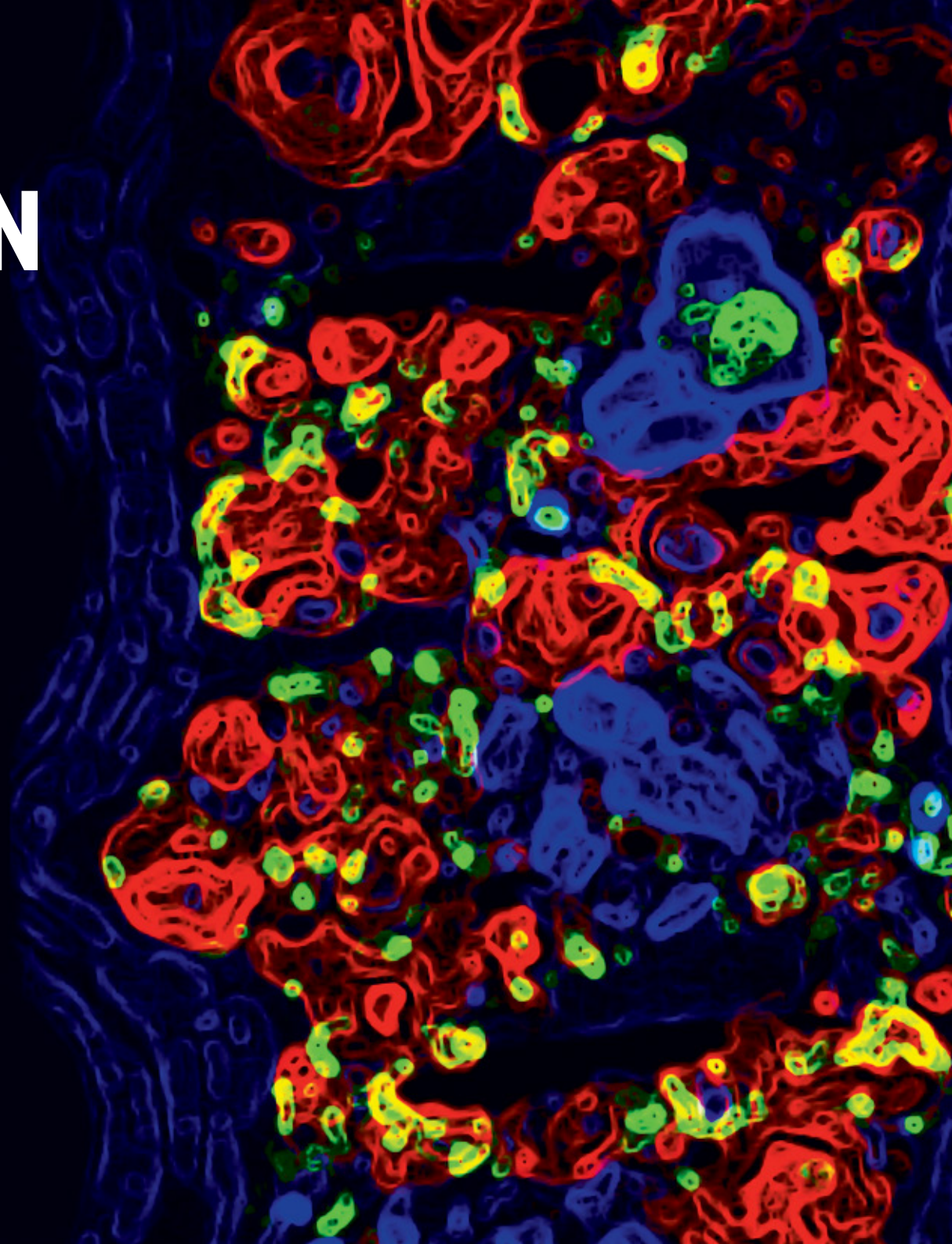
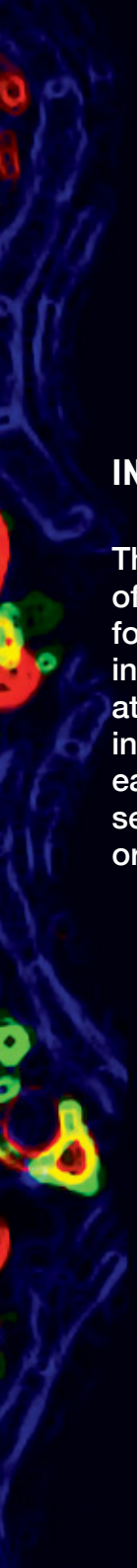


Image. NanoSIMS image showing distributions of iron, sulphur and phosphorus in the skeletal muscle of a patient with a myopathy. Dr Haibo Jiang, UWA



GLOBAL IMPACT LEADERS

INTERNATIONAL

The AMMRF is at the forefront of the international trend for collaborative research infrastructure. Our reputation attracts high quality international researchers from early career researchers to senior professors to come to, or return to, Australia.

DNA ORIGAMI

"My research is at the intersection of physics, chemistry and biology - we use DNA to make self-assembling nanostructures - called 'DNA origami'. To us, short DNA strands are like smart molecular lego pieces that can assemble themselves into the shapes we design. Because these are complex nanoscale objects, we require high resolution TEM and cryo-TEM to analyse them, which we achieve through the AMMRF. I began working in this area while at Oxford University for my PhD, and continued working on the biological applications of this in my post-doctoral position at Harvard Medical School. Access to high quality EM and optical microscopy facilities is essential to my work, and was of key importance when considering my options for starting my independent research career as a group leader. The AMMRF facilities at the University of Sydney were a key feature in deciding to take up a position at this university, and in Australia."

DR SHELLEY WICKHAM

Professor Harry Messel Research Fellow in the Schools of Chemistry and Physics, University of Sydney.

INSTRUMENT EXPERT

"I am often asked why I was attracted to come and work in Australia and share my experience with the AMMRF. In my view, the AMMRF, with its expert nodes and flagships, is still the only functional national network in our field. When I was offered a position at an AMMRF node, even though the original flagship was getting to the end of its life cycle – it was the people, the scientific network and the potential sharing of ideas and innovative science and instrument development, which motivated me to join AMMRF. I hope that I can help develop AMMRF scientists."

PROF. ROGER WEPF

Director of AMMRF at the University of Queensland and President of the European Microscopy Society.

NanoSIMS IS ESSENTIAL

"I completed my PhD in Materials at University of Oxford, in the UK and continued there for a postdoctoral position working on nanoscale secondary ion mass spectrometry (NanoSIMS) for biomedical imaging. I was able to demonstrate high-resolution direct visualisation of lipids and peptides in cells and tissues. When a lecturership came up at the University of Western Australia in 2015 the AMMRF facilities there, particularly the NanoSIMS lab, were a key feature attracting me to move to Australia. My research interests are now focused on the development of new multiscale and multimodal analytical methods for better understandings of lipid transport and cellular cholesterol efflux mechanisms. The AMMRF flagship NanoSIMS is essential to this work."

DR HAIBO JIANG

Lecturer,
University of Western Australia

ENGAGEMENT

MYSCOPE OUTREACH AUSTRALIAN LAUNCH

Our STEM engagement website, MyScope Outreach, was officially launched in Australia on 5 May at Questacon's Ian Potter Foundation Technology Learning Centre in Canberra.

MyScope Outreach was also promoted at the 2017 Conference of the Australian Science Teachers Association and received an extremely positive response.

THIS YEAR MYSCOPE OUTREACH WAS USED IN 150 COUNTRIES AROUND THE WORLD BY 33,000 PEOPLE

MOU (AMMRF + ACNP)

MOU

The AMMRF signed a Memorandum of Understanding (MOU) with the Advanced Characterization Nanotechnology Platform (ACNP) in Japan. The ACNP is a network of Japanese advanced microstructural characterisation facilities created to help address their scientific and technical challenges.

This MOU articulates a shared intent to encourage best practice and share new knowledge and techniques between the ACNP and the AMMRF.

Image. Dr Daisuke, ACNP and Prof. Julie Cairney signing the MOU.

GBI EXCHANGE OF EXPERIENCE

The AMMRF participated in the second Global BioImaging (GBI) Exchange of Experience workshop in Bangalore, India during September. It was hosted by the Indian GBI partners at the National Centre for Biological Sciences.

The meeting confirmed once again that Australia is leading the way in research infrastructure. It was the involvement of the AMMRF as mature and flourishing infrastructure that led to the success of the bid to the EU Horizon 2020 to establish GBI in 2015.

The next GBI Exchange of Experience meeting will take place in Sydney on 14–15 September, 2018 and will be hosted by the AMMRF and NIF as part of the GBI partnership.

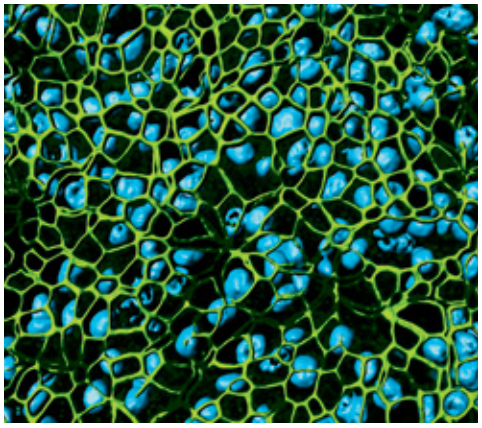
AMMRF's Collaboration Framework with Euro-BioImaging has been renewed for another two years.

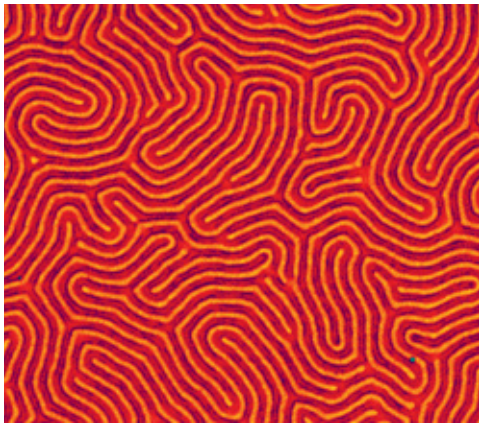
Image. Dr Jan Ellenberg, EBI and Prof. David Sampson signing the new Collaboration Framework.

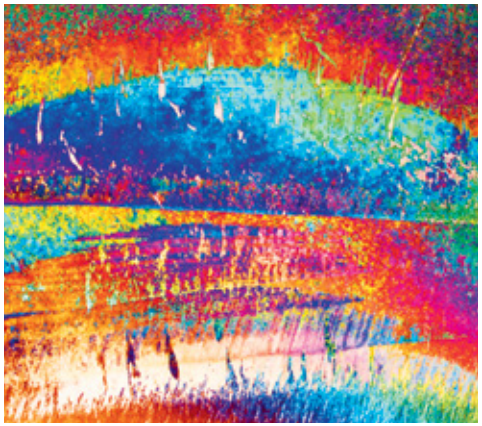
INCREDIBLE INNER SPACE

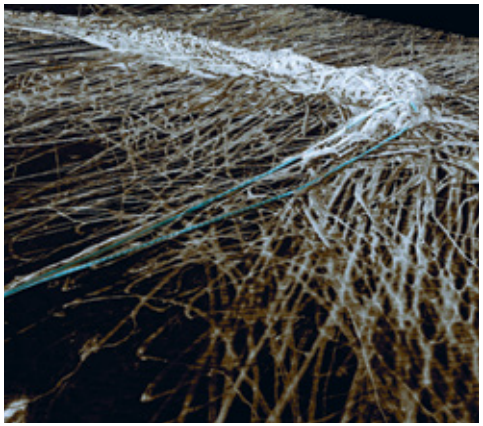
The AMMRF's Incredible Inner Space was on show in the Australian Embassy in Washington DC for six months in 2017.

Foreign Minster, the Hon. Julie Bishop, MP visited the exhibition and presented a short video for the Embassy social media. A number of Embassy events were held around the exhibition providing a focus, not only on the AMMRF and NCRIS's impact and outcomes, but those of Australian science and innovation.



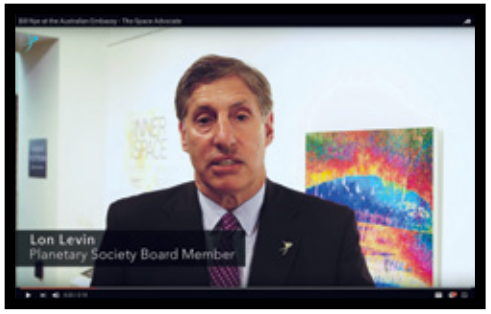






Visit ammrf.org.au/innerspace to see all of the exhibition images and details.

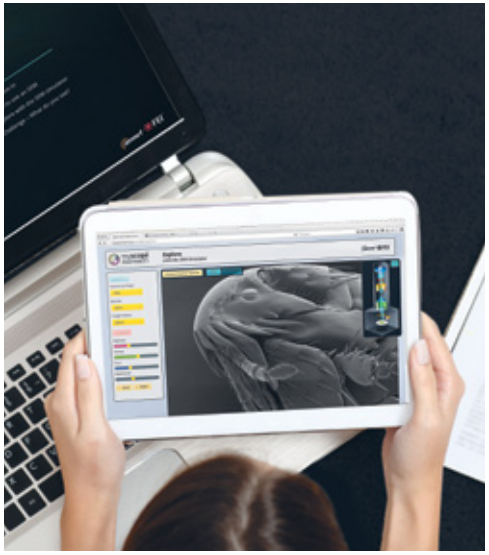
INCREDIBLE INNER SPACE > OUTER SPACE (USA + AU)



The Incredible Inner Space exhibition at the Australian Embassy In Washington DC was an ideal backdrop to a number of events promoting international collaboration. These included an event with Bill Nye, CEO of the Planetary Society, in conjunction with The Australian Government Department of Defence. They talked about present day space policy, and how the United States and Australia can work together in space and innovation technology. Filming amongst the Inner Space images provided a wonderful juxtaposition of inner and outer space science.

Australian and American alumni of Australian universities also met at the Embassy surrounded by the exhibition to hear guest speaker, Michael Brett, Co-Founder and CEO of US/Australian start-up QxBranch, who discussed the latest innovations in quantum computing technology and the emerging commercial ecosystem.

WORLD SCIENCE FAIR – BRISBANE



Our University of Queensland (UQ) team presented STEM outreach activities at the World Science Fair in Brisbane in March 2017. It included access to the MyScope™ Outreach website, USB microscopes and real bench-top scanning electron microscopes.

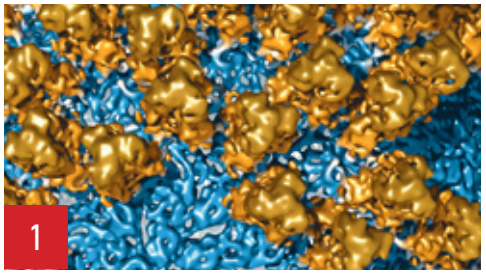
In a partnership with Hitachi HT two bench-top SEM's were made available to the public and demonstrated by Hitachi and AMMRF staff giving the visitors a real chance to dive into the micro- and nano-world and share our fascination of how nature is organised.

Dr Kim Sewell from UQ said, "Myscope™ Outreach, particularly the SEM simulator, was an excellent vehicle to attract and engage kids." More than 50,000 people passed through the Museum over the weekend of the Fair.

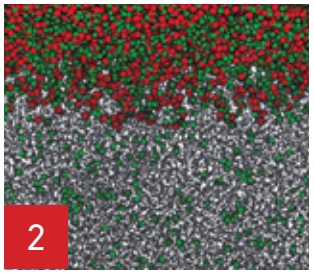
OUR DEVELOPMENTS I

Transmission Kikuchi diffraction (TKD) image of a severely deformed aluminium alloy with nanocrystalline shear bands cutting across large, deformed original grains. The colours indicate the orientation of the crystal lattice at each point in the map. Dr Pat Trimby, University of Sydney.

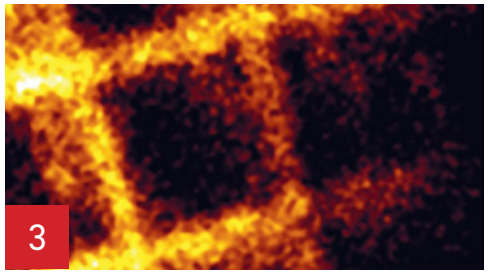
NFLUENCE THE WORLD



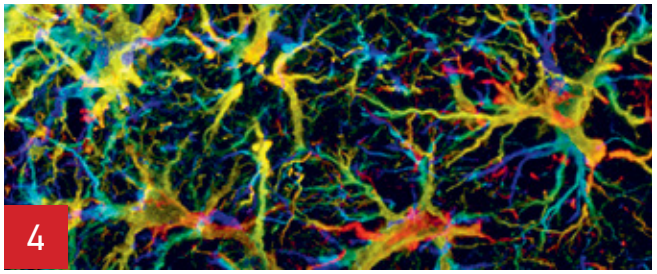
VIRUS-LIKE NANOPARTICLES FOR TARGETED DRUG DELIVERY



OVERCOMING SULPHUR CONTAMINATION

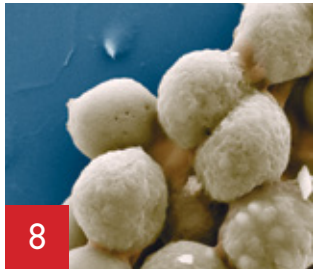


ENABLING T-CELL THERAPIES

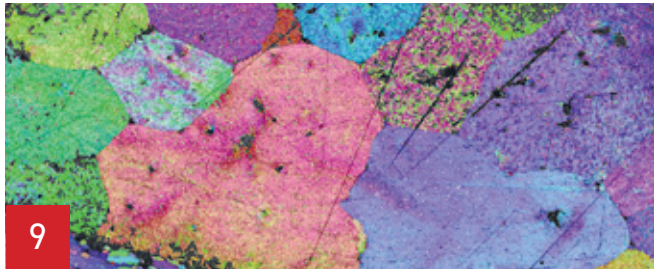


BIOMATERIALS FOR BRAIN REPAIR

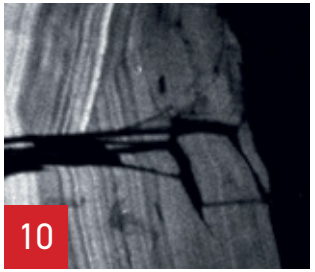
RACING TO IDENTIFY PIGEON VIRUS OUTBREAK



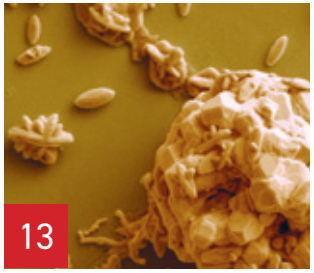
NEW CLOTTING MECHANISM DISCOVERED



METAL-CERAMIC COMPOSITES



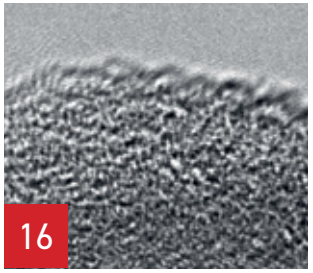
CONCENTRATING GOLD



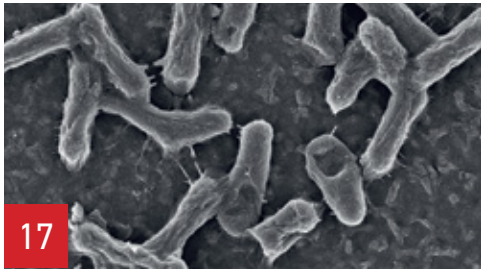
SYNTHESISING NEW NANOMATERIALS FROM LIQUID METALS

LOOKING INTO NANOWIRES

BIOCHAR – FROM GARBAGE TO AGRICULTURAL BOOSTER



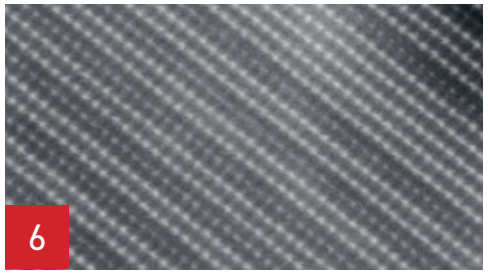
SUPERTHIN METAL OXIDE NANOSHEETS FOR ELECTRONICS



NEW WEAPON AGAINST SUPERBUGS

5

SOLAR PHONE



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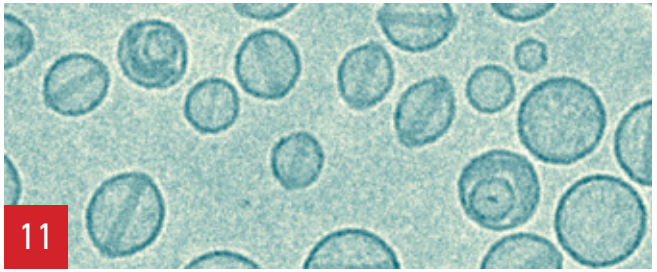
HUNTING OBSCURE MINERALS



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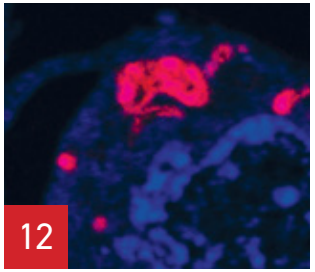
SUPPORTING SMES – VISUALISING LIPOSOMES



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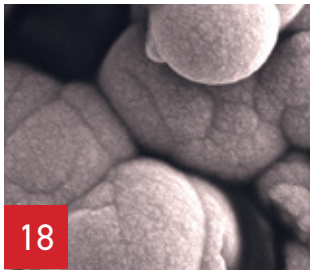
SUBCELLULAR DRUG TRACKING



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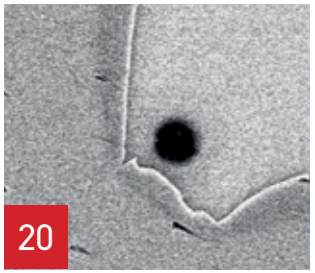
ULTRA-HIGH RESOLUTION ANALYSIS OF BIOMARKER VESICLES

19

SUPPORTING INDUSTRY – SILANNA



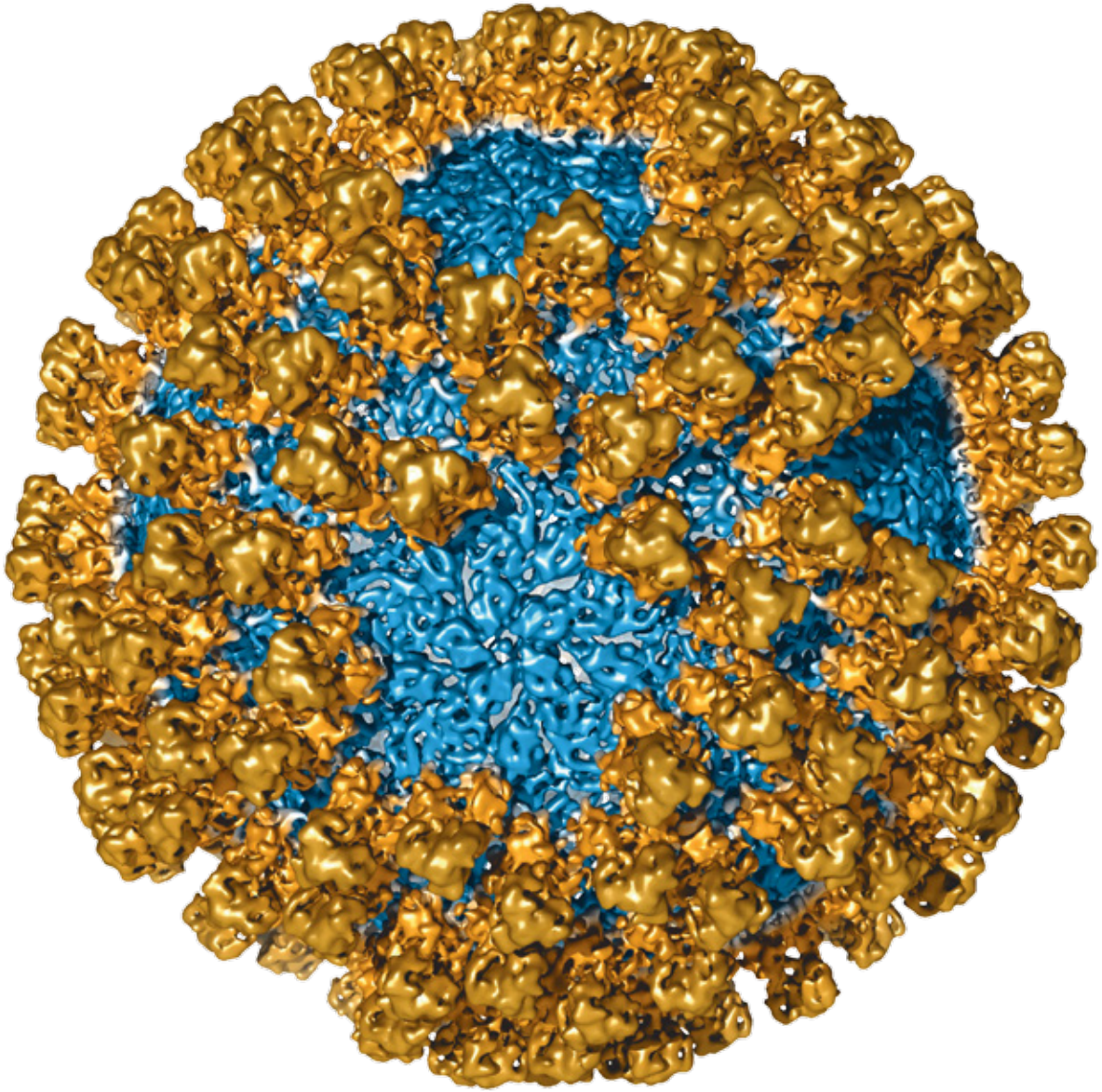
20

HIDDEN CLUES TO ORE FORMATION

RESEARCH OUTCOMES & SOCIAL IMPACT

Take a closer look at this year's research highlights – all enabled by AMMRF microscopy. With over 3,000 researchers annually, here are just a few of our recent stories.

2017



3D reconstruction of cryo–EM data showing the VNP shell structure. The VNP is approximately 62nm in diameter.

1

VIRUS-LIKE NANOPARTICLES FOR TARGETED DRUG DELIVERY

CHALLENGE

New kinds of drugs and other therapeutic molecules are useless if they can't be delivered effectively to the parts of the body where they need to function. The more targeted this delivery can be, the lower the amount of the drug that can be used since it will be concentrated at the target site. This results in fewer side effects for the patient. Development of carriers for effective drug delivery is the subject of extensive research. Scalable, easy-to-manage production methods are highly sought after.

SOLUTION

Viruses are nanoscale infectious agents containing genetic material packaged within a coat of proteins. This structure can be manipulated to produce empty shells without the infectious genetic component. These virus-like nanoparticles (VNPs), are potentially useful for drug delivery.

Researchers at the University of Queensland (UQ), led by Drs Frank Sainsbury and Michael Landsberg have made VNPs by directing plant cells, from the Australian native plant, *Nicotiana benthamiana,* to produce the coat proteins from the blue-tongue virus (BTV). This plant system is easy to work with and repeatedly produces good yields of viral proteins. These readily self-assemble into structures that are almost identical to the infectious agent, but are completely benign as they lack the genetic material.

The manipulated VNPs were designed to be either empty or to incorporate a fluorescent protein (GFP), as a marker to check whether proteins could be incorporated without disrupting the distinct shape of the particles. Cryo-electron microscopy in the AMMRF at UQ was used to verify the VNP structure, which was found to be highly consistent and like that of the whole virus.

This is encouraging since future developments of this system for incorporating therapeutic proteins into these particles could now be well within the realms of possibility. The team was also able to take advantage of a naturally occurring pore in the VNPs to introduce small fluorescent dye molecules into the centre of the particle. This broadens the potential drug delivery options to include small molecules as well as proteins.

Variation in the levels of specific proteins produced by some tissues and cancers can be exploited to target particles to the correct cells in the body. The BTV VNPs were found to naturally stick to a cell-surface protein called integrin. Integrin is over-produced in cancerous tissue, potentially making BTV VNPs effective carriers for cancer treatments.

The plant systems used in this work could also be used to understand the structure of new and emerging viruses. The coat protein genes could be isolated and the proteins produced in the plant system for structural studies without having to deal with whole infectious virus particles.

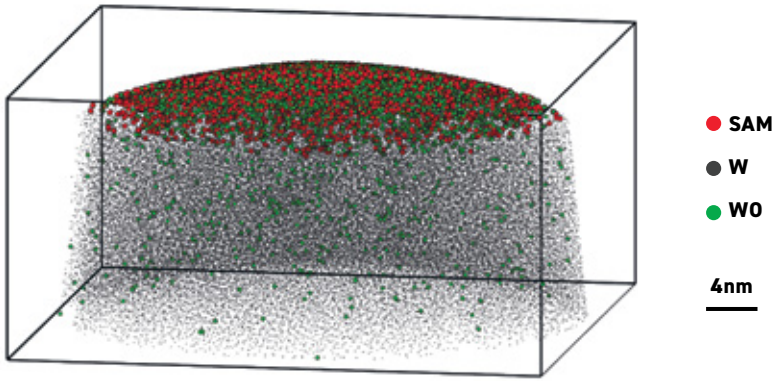
IMPACT

Production of BTV VNPs in plants offers:

- an easy, efficient and safe way to produce high quantities of multiple viral coat proteins
- ability to rapidly assess coat protein modifications
- high fidelity assembly of the virus-like particles
- a flexible drug delivery platform
- a safe way to study emerging virus coat structures

Ref. L. Brillault, et al., 2017, ACS Nano, 11(4), 3476

2 OVERCOMING SULPHUR CONTAMINATION



Some metals are used as catalysts to help facilitate chemical reactions. Fuel cells for example use platinum to help generate energy from the fuel. Sulphur is a contaminant in many types of fuels and can attach to the surface of the metal particles. This can cause the reactions to slow down or stop completely, resulting in severe costs due to the downtime needed to replace or reactivate the catalyst. It has been difficult to determine how sulphur bonds to the metal, and therefore how it blocks the catalytic process.

Katja Eder from the University of Sydney (USyd) employed the nanoscale resolution of flagship atom probe tomography (APT) in the AMMRF at USyd to analyse sulphur–metal bonding for the first time. Needle-shaped specimens with a tip diameter of less than 100 nm were prepared from the common catalysts tungsten, platinum and aluminium.

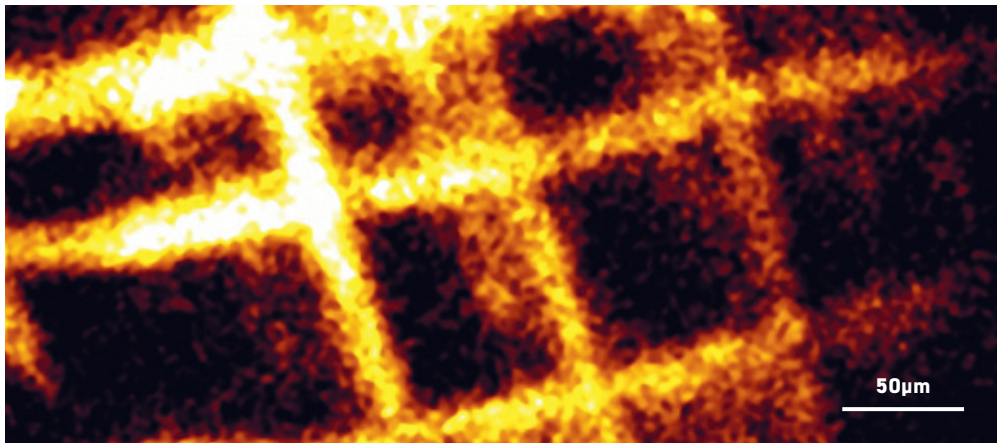
They were then dipped in a sulphur-containing compound, under controlled atmosphere in a specially designed transfer system to ensure no oxygen was present to oxidise the metal. This generated a tip coated with a single layer of sulphur.

Analysis revealed that different metals bound sulphur quite differently. Bonding was also affected by surface oxidation. Understanding the conditions that affect how sulphur bonds to different metals will enable researchers to design composite nanoparticles that could modulate how strongly sulphur bonds to the surface. This could improve catalytic performance and maximise the particles' functional life. This in turn can influence the effectiveness and economic viability of fuel cells and other catalytic devices.

Image: 3D APT reconstruction showing the atomic distribution at the tip of a sulphur-coated tungsten specimen. Sulphur is red, tungsten is grey and oxidised tungsten is green.

Ref. K. Eder et al., 2017, Langmuir, 33, 9573

3 ENABLING T-CELL THERAPIES



T-cells are an important part of the human immune system and of great interest for new therapeutic applications in human medicine. Immunotherapy with specialised T-cells could be used to combat autoimmune disease, enhance tolerance to organ transplants and to target cancer. One of the most significant hurdles to the affordable delivery of these cell therapies is the cost and difficulty of expanding T-cells to clinically significant numbers.

A team comprising researchers from the Collaborative Research Centre for Cell Therapy Manufacturing, the Universities of South Australia (UniSA) and Adelaide, the Women's and Children's Hospital, and the Queensland University of Technology, led by Prof. Nicolas Voelcker and A/Prof. Simon Barry have tackled this problem. They've designed and developed 3D-printed micrometre-scale cell-culture lattices coated with molecules that trigger T-cell proliferation.

The lattices facilitate production of a range of therapeutic human T-cell types including regulatory, helper and killer T cells, maintaining their correct functions as they proliferate.

The researchers used the flagship time-of-flight secondary ion mass spectrometer and X-ray photoelectron spectrometer in the AMMRF at the UniSA to characterise and optimise the bioactive molecular coatings on the cell-culture lattices.

This lattice format developed by the team can also be feasibly incorporated into existing cell culture environments, and the technology is currently being translated into commercial applications. The cell expansion platform is user-friendly and expedites cell collection and scale-up, making it ideal in the future for translating T-cell therapies from bench to bedside.

Image: XPS imaging of molecular coatings (yellow) on the 3D printed lattice.

4 BIOMATERIALS FOR BRAIN REPAIR

Star-shaped brain cells called astrocytes, protect the brain through a complex response after traumatic injury. After injury the astrocytes dramatically change shape and function, releasing inflammatory molecules and ultimately causing scarring of the surrounding brain tissue.

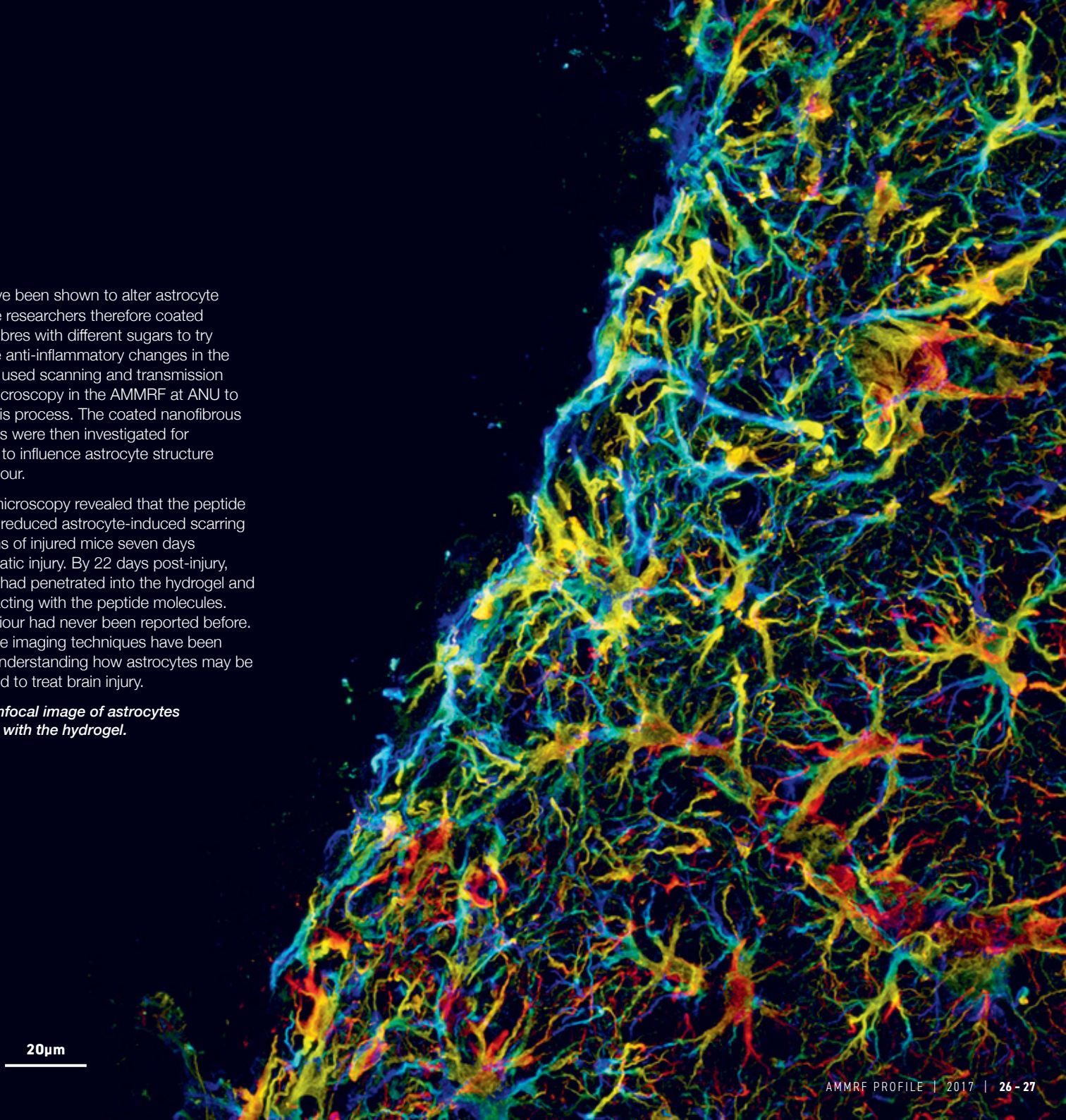
To help ameliorate scarring and aid functional recovery of the brain after injury, researcher Francesca Maclean working with Dr David Nisbet at the Australian National University (ANU) is exploring biomaterials that could influence the behaviour of astrocytes. If successful these materials could eventually lead to implantable new treatments for patients with brain injuries.

Ms Maclean investigated biocompatible polycaprolactone nanofibres and peptide nanofibre hydrogels as materials that could be used as 3D cell culture scaffolds to mimic brain structure. These would enable studies of nerve cell behaviour, and development of treatments for brain injury and disease.

Sugars have been shown to alter astrocyte shape. The researchers therefore coated their nanofibres with different sugars to try and induce anti-inflammatory changes in the cells. They used scanning and transmission electron microscopy in the AMMRF at ANU to visualise this process. The coated nanofibrous biomaterials were then investigated for their ability to influence astrocyte structure and behaviour.

Confocal microscopy revealed that the peptide nanofibres reduced astrocyte-induced scarring in the brains of injured mice seven days after traumatic injury. By 22 days post-injury, astrocytes had penetrated into the hydrogel and were interacting with the peptide molecules. This behaviour had never been reported before. The multiple imaging techniques have been crucial in understanding how astrocytes may be manipulated to treat brain injury.

Image. Confocal image of astrocytes interacting with the hydrogel.



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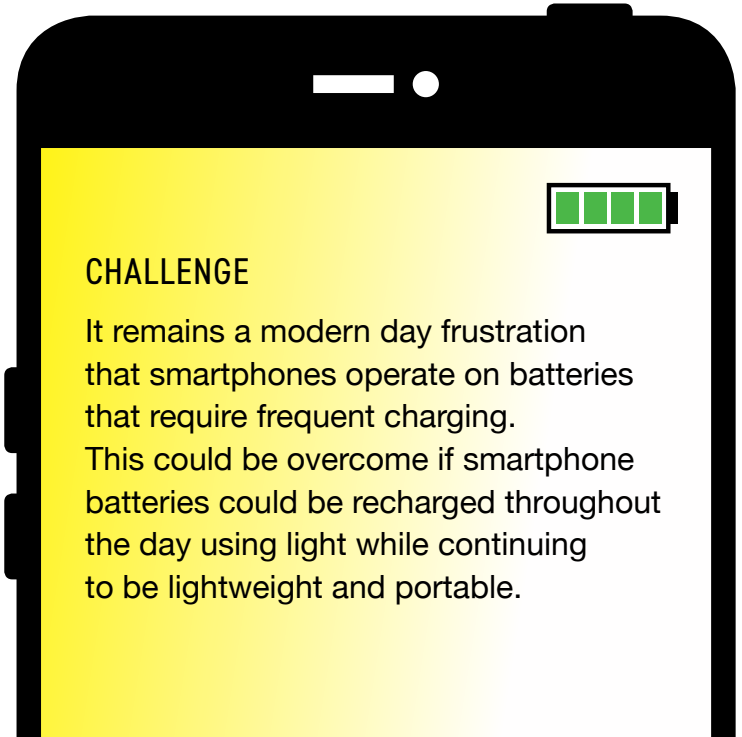
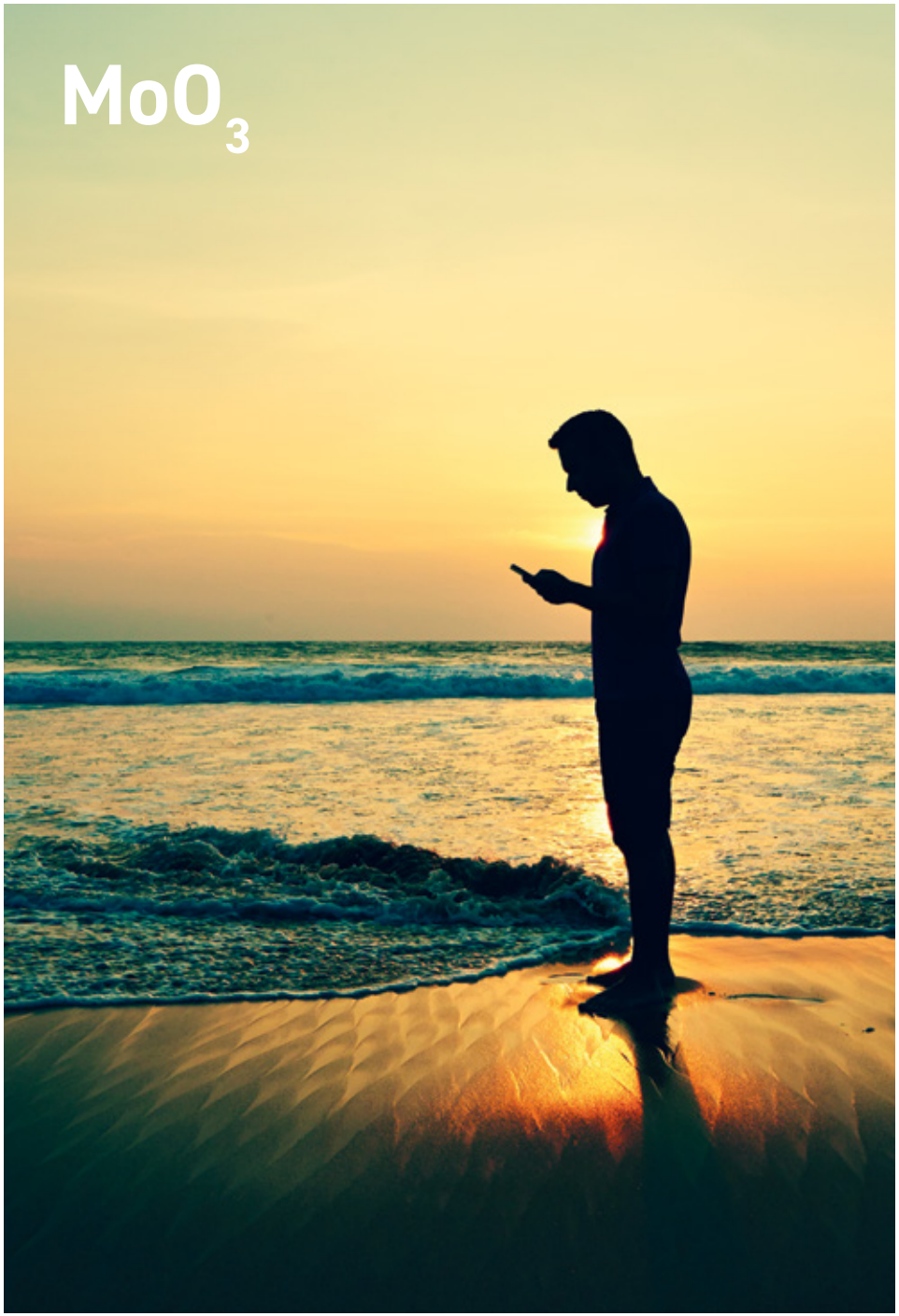
SOLAR PHONE



CHALLENGE

It remains a modern day frustration that smartphones operate on batteries that require frequent charging.
This could be overcome if smartphone batteries could be recharged throughout the day using light while continuing to be lightweight and portable.



SOLUTION

Dr Yung Hau Ng and Prof. Rose Amal at the University of NSW (UNSW) are developing solar battery technology that could enable direct recharging of mobile phones using light, and without the need to mount solar panels onto the battery or the device. Their design is an all-in-one solar powered and energy storing device. It is based on a thin film electrode of molybdenum trioxide (MoO_3) interfacing with an electrolyte rich in sodium ions.

The MoO_3 layer acts as both a solar cell and a negative battery terminal. Rather than using the power supply to charge the battery, the solar-rechargeable battery uses light energy to dislodge electrons from the MoO_3 layer. This draws sodium ions into the MoO_3 layer, where they are stored, thus charging the battery. When the battery is in use, the sodium ions and electrons are released, producing current to operate the phone.

This system is distinct from those where light harvesting and energy storage are realised, with limited efficiencies, by separate or hybrid technologies such as solar cells and batteries.

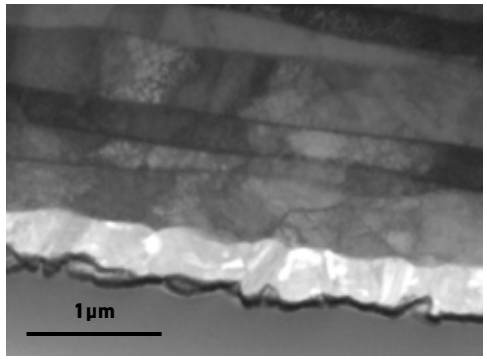
To ensure the thickness of the MoO_3 was optimised in delivering the functions of light capture, energy storage and conversion, the researchers employed microscopy in the AMMRF at UNSW. They prepared a thin slice of the film with a focussed ion beam for examination in a transmission electron microscope and confirmed that the optimal thickness of 300 nanometres had been achieved.

IMPACT

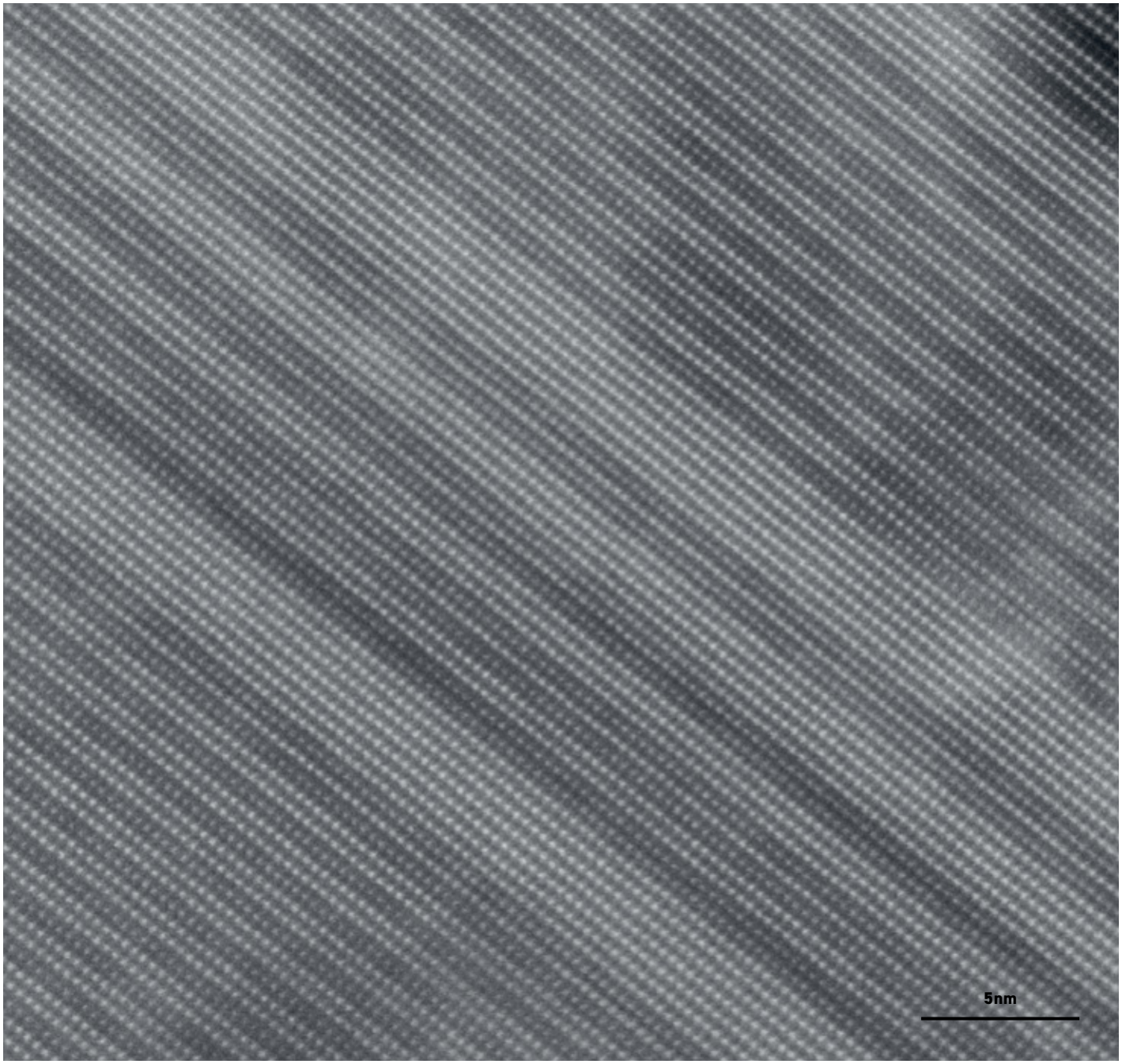
This newly synthesised battery terminal is a crucial step in realising a lightweight, solar-rechargeable phone. It would eliminate the need for supplying and carrying phone chargers, greatly reducing production costs and enhancing phone portability and effectiveness.

THE GROWING MOBILE PHONE INDUSTRY IS ESTIMATED TO HAVE CONTRIBUTED $USD 3.3 TRILLION TO GLOBAL GDP IN 2016.

This innovative research into consolidated mobile phone functions and components will help to leverage this global market, yielding increasingly convenient and greener devices.



Focussed ion beam prepared cross section showing the MoO_3 film (white), grown on a Mo substrate. The average thickness of the film was measured by performing an elemental line scan across the section.



6 HUNTING OBSCURE MINERALS

Searching for minerals requires significant investments of time and capital. This could be minimised by establishing the conditions in which the target minerals are formed underground making for easier identification at the surface. Formation conditions can be inferred substantially from their final composition and crystal structure.

Bastnäsite-synchysite group (BSG) minerals, which are abundant throughout the Olympic Dam deposit in South Australia, and further afield, are able to reveal such information. The BSG comprises mixed-layered compounds formed by rare-earth-element (REE) fluoro carbonates. They incorporate REE- and calcium-rich layers that have various crystal lattice structures and compositions. These minerals have a range of applications in research and industry.

Funded by BHP Olympic Dam, Dr Cristi Ciobanu at the University of Adelaide used the AMMRF's instruments and expertise in advanced transmission electron microscopy (TEM) on these samples, prepared by focussed ion beam milling. This allowed for atomic-scale insight into the structure of these minerals. While doing this, a number of other structures were also identified, based on patterns in the stacking of atomic layers. The layers are differentiated as lighter and darker lines of atoms in the high-angle annular dark-field scanning TEM image.

Atomic-scale imaging showed that the composition of minerals from the Olympic Dam site lay between bastnäsite and a mineral called parisite, and included a new BSG structure. All these structures exhibited short-range disorder in their atomic stacking, and indicate that highly unsettled conditions were present during mineral formation. The observations are expected to lead to more accurate searches for otherwise obscure mineral deposits.

Image: High-angle annular dark-field scanning TEM image of an Olympic Dam sample.

Ref. A. Kontonikas-Charos, et al., 2017, Ore Geology Reviews 80.

PROTECTING OUR NATIONAL POULTRY INDUSTRY – WORTH OVER $5.6 BILLION P.A.

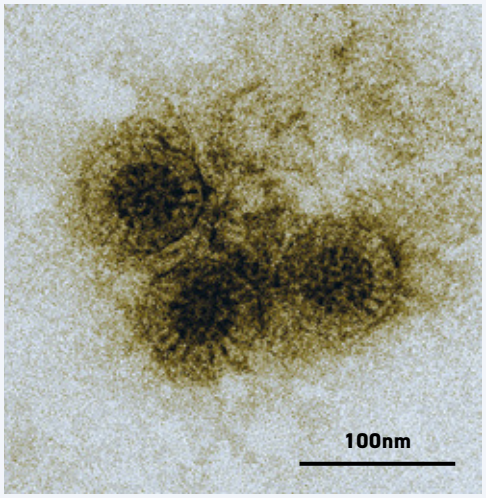
7 RACING TO IDENTIFY PIGEON VIRUS OUTBREAK

In mid 2016, Western Australian owners of hobby and racing pigeons reported large numbers of birds in their lofts presenting with signs of disease. In some lofts, up to 30% of infected birds were dying within a week of exhibiting signs of sickness. Infected lofts were soon reported all over Australia, sending the Australian pigeon industry into a flap.

To investigate the cause of the illness, extensive testing was conducted in conjunction with the Department of Agriculture (WA), AgriBio (VIC) and CSIRO Australian Animal Health Laboratories (AAHL). Following a provisional diagnosis of viral hepatitis, molecular testing suggested the disease was due to viral infection.

Dr Megan Dearnley and Sandy Crameri at the AMMRF linked laboratory transmission electron microscope facility at AAHL, analysed the infectious particles confirming them to be viral, of the rotavirus family Reoviridae. This virus presented with a characteristic appearance with no membrane surrounding the virus, and white spikes projecting from an electron dense core that measured around 73 nanometres, which is common for this family of viruses.

Following diagnosis via electron microscopy, further targeted DNA analysis confirmed the presence of an active rotavirus. Diagnosis of this mystery pigeon virus helped inform authorities and veterinarians of the causative agent of disease and assisted in providing biosecurity recommendations for the industry. Furthermore, fast identification of this emergent avian viral species was critical in protecting our national poultry industry, estimated to be worth over $5.6 billion p.a.. The virus continues to circulate, but the number of cases have now subsided significantly.



Transmission electron micrograph of pigeon rotavirus particles.

8

NEW CLOTTING MECHANISM DISCOVERED

CHALLENGE

Critical illness caused by sepsis, trauma, cardiogenic shock, transplant rejection and severe haemorrhage is often complicated by the development of systemic inflammation and major organ injury. The lungs are particularly susceptible.
A severe reduction in blood flow (ischaemia) to the intestines can trigger blood clot formation in many other organs, including the lungs. The resulting lung injury develops into acute respiratory distress syndrome (ARDS), from which around 90% patients die. No effective treatments or preventatives exist for this lethal condition: conventional anti-platelet therapies such as aspirin do not work. It is currently not clear how lack of blood flow to the gut causes blood clots in the lungs.

Understanding this process could lead to effective therapies to reduce remote clots in these critically ill patients and deliver more favourable outcomes.

SOLUTION

Dr Yuping Yuan, Imala Alwis and colleagues working with Prof. Shaun Jackson at the Heart Research Institute at the University of Sydney used a combination of microscopy techniques to study clot formation in samples from ARDS patients and mice.

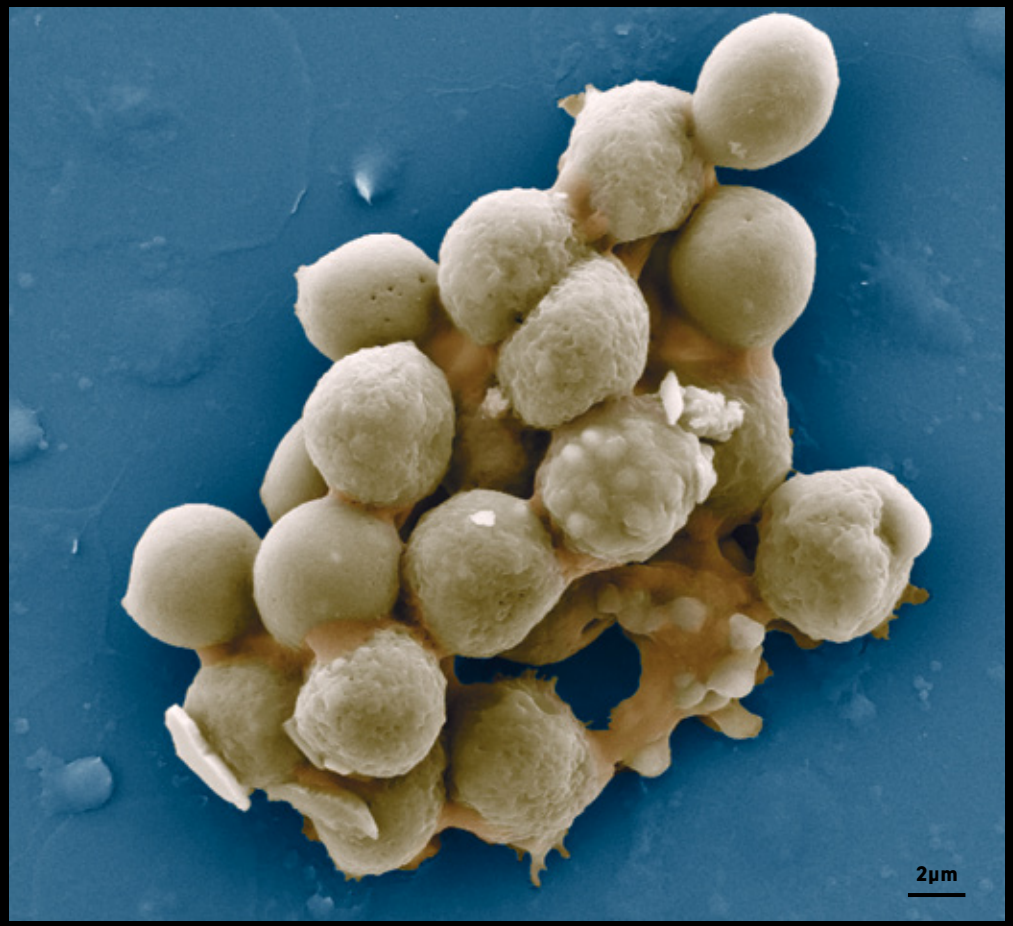
They showed that during gut ischaemia, clot-forming platelets die. Real-time confocal microscopy of the intestinal micro blood vessels during reduced blood flow revealed that rolling white blood cells called neutrophils grab and rip large membrane fragments from dying platelets as they pass by. These dead platelet fragments stick to adjacent neutrophils to form large aggregates that have the ability to obstruct blood flow. This previously unrecognised blood clotting mechanism links gut ischemia to remote lung injury. The team used scanning electron microscopy in the AMMRF at the University of Sydney to confirm the bridging capabilities of these dying platelet fragments in forming the neutrophil aggregates.

Although these clots are not amenable to conventional anti-platelet therapies, the protein cyclophilin D, which regulates cell death, was found to prevent neutrophil aggregation and clot formation in the lungs. This therefore identifies a new target pathway for potential drug therapies.

IMPACT

This newly identified clotting mechanism could lead to development of effective therapies that target lung clots in critically ill patients. This could save up to 12,500 lives per year in Australia alone.

Ref: Y. Yuan et al., 2017, Sci. Transl. Med., 9(409).



Scanning electron micrograph showing an aggregate of neutrophils. Imala Alwis.

THIS COULD SAVE UP TO 12,500 LIVES PER YEAR IN AUSTRALIA ALONE

9 METAL–CERAMIC COMPOSITES

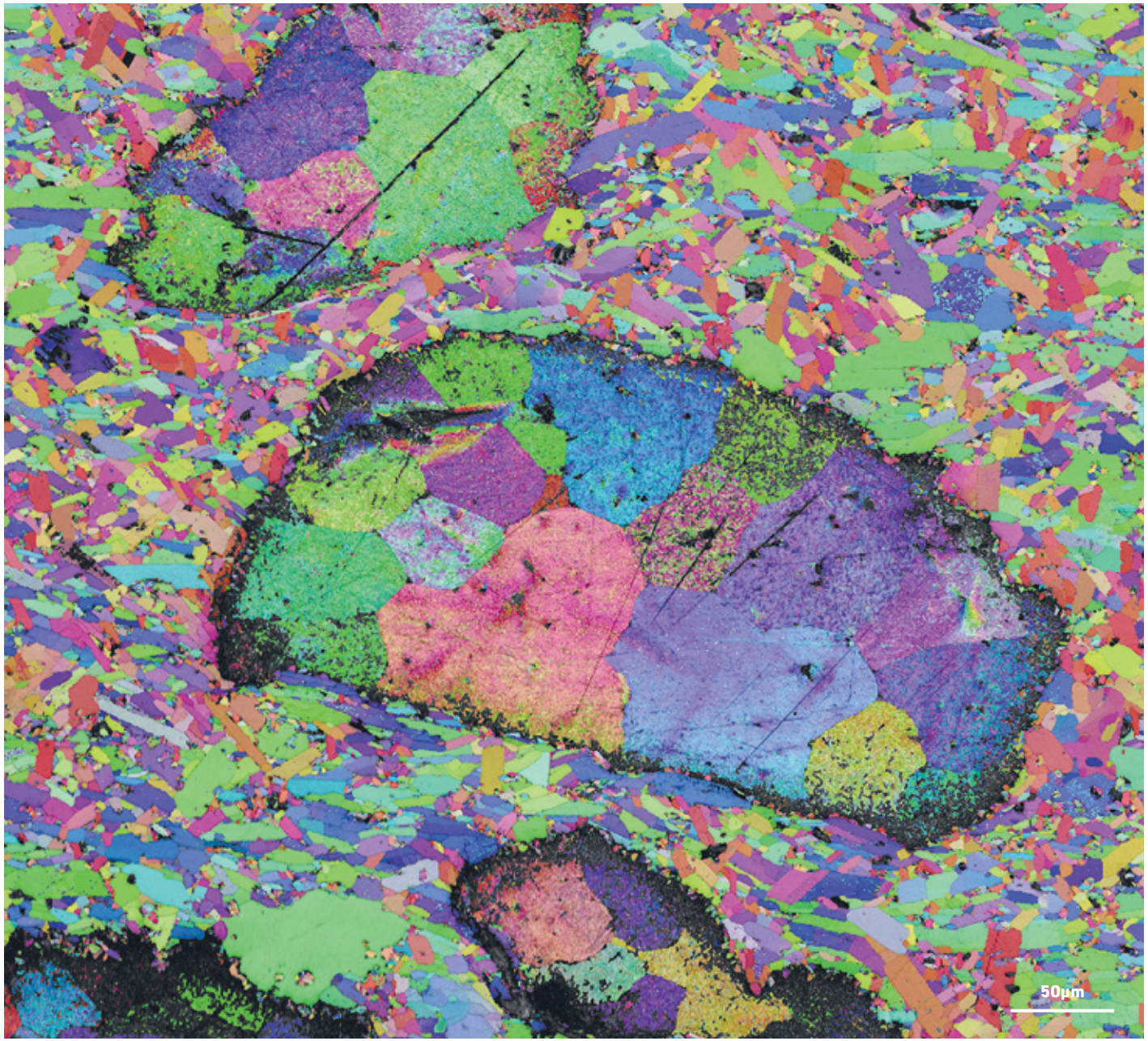
The aerospace and transport industries are interested in lightweight materials able to perform at high temperatures for use in engines and turbines. New aluminium alloys have been developed in the last few decades to help reduce the weight of current planes but their mechanical properties at high temperatures are still not sufficient for the new generation of commercial and military aircraft.

A/Prof. Gwénaëlle Proust from the University of Sydney (USyd) and collaborators at Texas A&M University have been working on a solution to this problem. They are developing new composite materials made by combining lightweight aluminium with a high-performance ceramic. These composites are fabricated by making a titanium carbide ceramic foam that is then infiltrated by molten aluminium. When tested in compression, the composite displayed exceptional mechanical properties at both ambient and elevated temperatures.

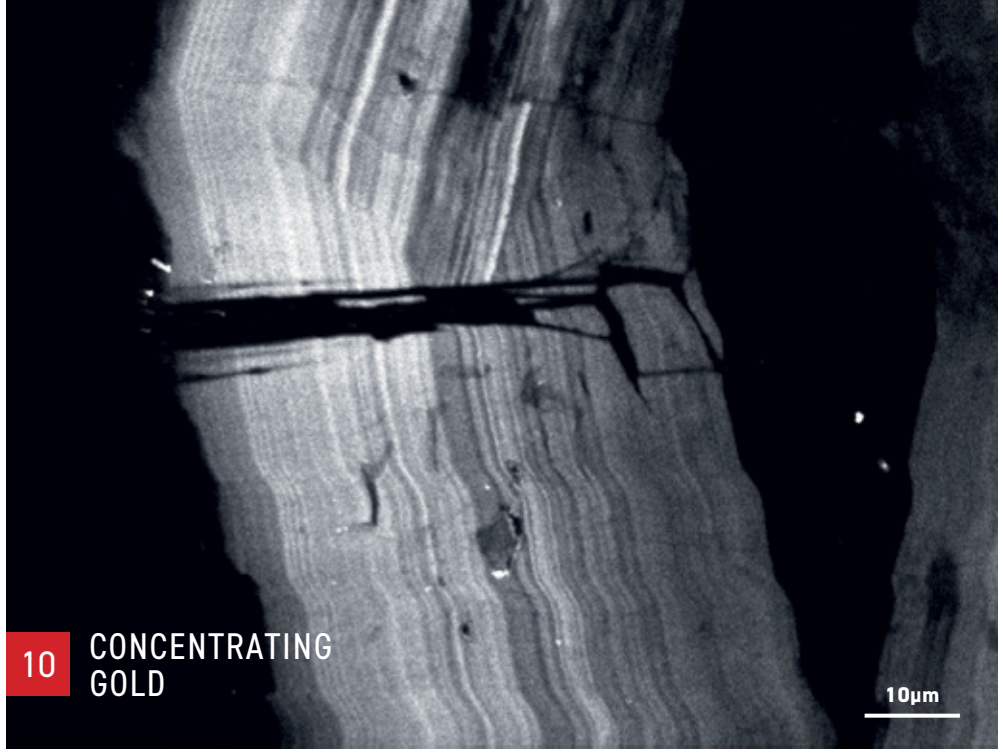
Compared to the corresponding aluminium alloy, the composite achieved a compressive strength ten times higher at ambient temperature and 14 times higher at 400 °C. Electron backscatter diffraction and X-ray microtomography in the AMMRF at USyd, carried out before and after mechanical testing, revealed that there was an even distribution of the two phases with the pores perfectly filled with aluminium. They also showed that the composite structure was not significantly affected by heating.

The initial success with these metal–ceramic composites opens the way to fulfilling the requirements of next-generation aircraft. By controlling the processing parameters, it will be possible to control the microstructure of the composites and therefore to optimise the material for specific applications.

Ref. L. Hu et al., 2016, Sci Rep. 6. Article no. 35523



Electron back scatter diffraction image of the fabricated ceramic composite. The colour of each grain indicates its orientation in the substrate. The pore in the centre of the image is completely filled with larger aluminium grains.



10 CONCENTRATING GOLD

Despite the economic importance of mining for Australia, there is a knowledge gap around the fundamental physical and chemical processes that form and transform ore deposits. These processes operate at the micro- to nano-scale so new, innovative characterisation technologies are needed to fill this knowledge gap. A better understanding of these processes can provide an opportunity to optimise extractive metallurgy workflows.

To address this gap, Dr Denis Fougerouse and colleagues from Curtin University, the University of Western Australia (UWA) and CSIRO conducted a study of gold-bearing ores from Ghana by using a correlative microscopy approach in the AMMRF at UWA, the Australian Synchrotron and using Curtin's own instruments. The results integrate data from the centimetre to the atomic scale including synchrotron X-ray fluorescence microscopy, flagship nano-scale secondary ion mass spectrometry (NanoSIMS) and atom probe microscopy.

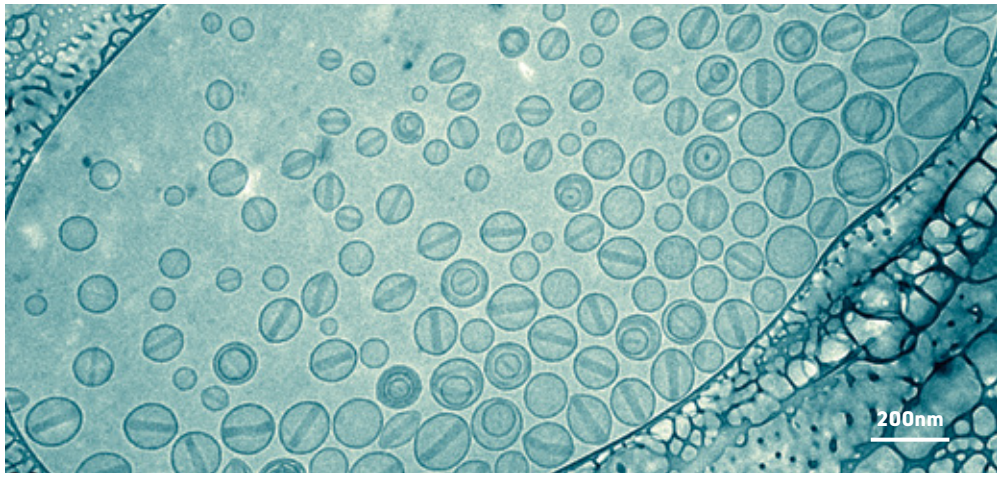
The combined data built up a picture of how ultra-high grade gold veins are created amongst areas with a much lower gold concentration. They found that a complex chemistry operates, which can solubilise gold in one location and then deposit it close by. As gold-bearing rocks were deformed, nickel-rich fluids moved into cracks replacing some of the gold with nickel. The released gold moved out into the fluid and, depending on the concentration of sulphur, was deposited over distances of ten micrometres to many metres as the fluid moved through the network of cracks to form high-grade ore shoots.

Applying this new data and characterisation workflow to ore minerals opens up new ways to understand processes operating during mineralisation.

Image: NanoSIMS map of the gold distribution in an arsenopyrite mineral from the Obuasi deposit, Ghana.

Ref. Fougerouse, D. et al., 2016 Geochimica et Cosmochimica Acta 178.

11 SUPPORTING SMES – VISUALISING LIPOSOMES



Lipotek was established as a spin-off from the Australian National University to commercialise intellectual property relating to a nanoparticle-based vaccine for melanoma that targets dendritic cells, a specialised part of the immune system. The company has now focussed on vaccine and chemotherapy drug delivery with its eyes set on the global injectable drug delivery market predicted to reach USD 931.1 billion by 2024.

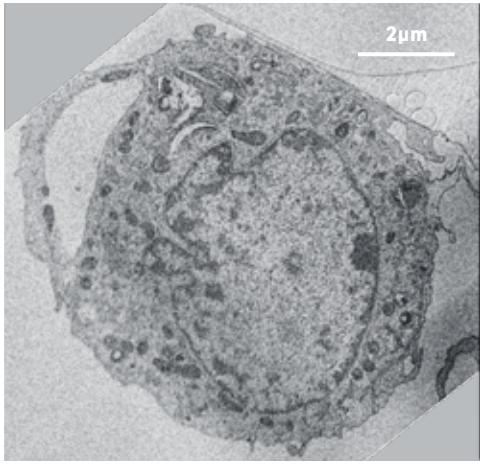
Their researchers developed customisable fat-based, drug delivery particles called liposomes, which are less than 200 nanometres in diameter. The liposome coat protects the contents from degradation and extends circulation time in the blood. It can also incorporate specific molecules that direct delivery to the intended target cells.

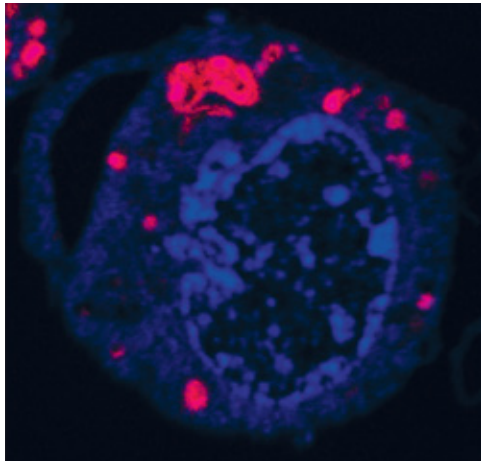
The AMMRF at the Australian National University (ANU) has supported Lipotek in developing and optimising its liposomes. AMMRF's expertise has been used to develop new and effective methodologies to prepare the drug-loaded liposomes for visualisation by cryogenic transmission electron microscopy (cryo-TEM). This technique clearly showed that the drug consistently filled the liposomes with crystalline rods. Confocal microscopy was also used to confirm the uptake of loaded liposomes by immune cells. Researchers used additional imaging techniques in whole mice to show that the liposomes accumulated in and around targeted tumours.

Lipotek has now partnered with local and international collaborators, in academia and industry, to validate its liposomes as a vaccine delivery platform to combat tuberculosis and malaria. They also have a long-term association with the Indonesian vaccine manufacturer PT Bio Farma.

Image: CryoTEM image of drug-loaded liposomes.

12 SUBCELLULAR DRUG TRACKING





To accurately predict the pharmacological effect of potential drugs, the pharmaceutical industry needs to image the location of drugs within cells and intracellular compartments. This is needed to answer questions about whether drugs are sufficiently concentrated in the right places to have a therapeutic effect, or if the medicine is lodging in cellular components that make it functionally inaccessible. If anomalies are spotted early in the developmental pathway, it could help to explain toxicities or lack of efficacy and reduce costly late-stage drug development failures.

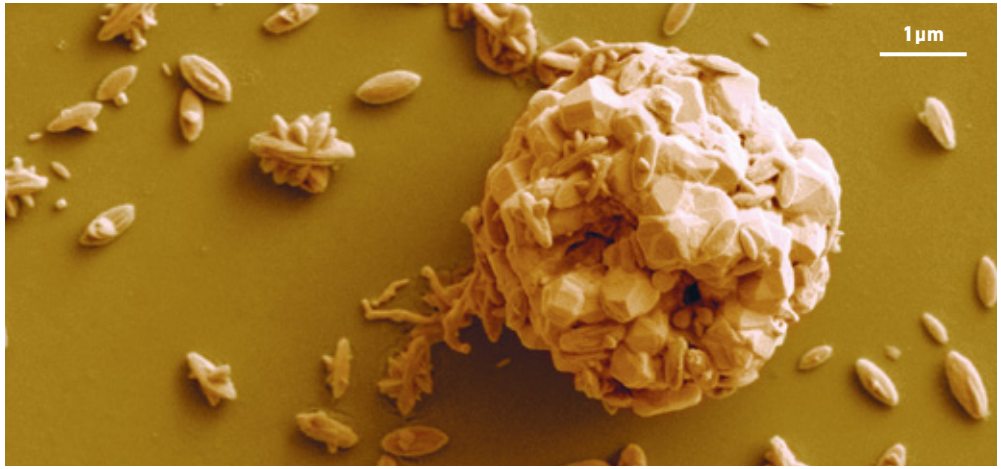
Dr. Haibo Jiang from the University of Western Australia (UWA) with collaborators from the National Physical Laboratory, UK and GSK developed a method to conduct high-resolution correlative backscattered electron and nanoSIMS imaging that shows structural and chemical information on drug distributions on the same section of the same cell. This method allowed visualisation of the internalisation of the drug amiodarone by lung macrophages and showed that it accumulated in internal compartments called lysosomes.

Amiodarone is a drug used to treat and prevent irregular heartbeats. This family of drugs is able to easily cross cell membranes, making them very attractive from a pharmacological point of view. However, most of these drugs, including amiodarone, have been reported to induce phospholipidosis, a disorder leading to inflammation and dysfunction of a variety of cells and tissues. Using the method developed at UWA, the researchers also showed, with high-magnification correlative images, the first visual evidence of amiodarone-induced phospholipidosis and the colocalisation of amiodarone and membrane structures in the lysosomal lamellar bodies.

Image: Correlative back scattered electron (left) and nanoSIMS imaging (right), showing the morphology of the cells, and distribution of amiodarone (red) in lysosomes.

Ref: Jiang H, et al., 2017 Chemical Communications, 53.

13 SYNTHESISING NEW NANOMATERIALS FROM LIQUID METALS



Room temperature liquid metals, particularly those based on gallium, have received significant attention recently with new applications arising, including in light-assisted reactions, pumps without mechanical parts, heavy metal ion detection, self-repairing circuitry and self-healing materials. A/Prof. Anthony O'Mullane, from the Queensland University of Technology (QUT), has developed a technique for the isolation of nanostructured metallic gold from aqueous gold salts using liquid metal.

This will be a key step in the development of gold and silver nanostructures that use light to mediate and speed up a range of reactions. This has applications where the nanometals can be used to clean up water by degrading organic contaminants, such as dyes, present in industrial waste.

A/Prof. O'Mullane modified the surface of a liquid metal called Galinstan (70% gallium, 20 % indium and 10% tin) by immersing it into an aqueous gold salt solution.

This initiated a process where gallium was oxidised at the surface, providing electrons that reduced the gold salt to metallic gold. Under scanning electron microscopy (SEM), transmission electron microscopy (TEM) and elemental analysis in the AMMRF's linked laboratory at QUT, it was found that gold ions were recovered from the solution as nanostructures on the surface of the liquid metal. The same process was demonstrated for recovering silver nanoparticles.

Additionally, when the liquid metal was vibrated using ultrasonic waves, microdroplets formed, and as the oxidation process was repeated, structures resembling 'nano-rice' were observed, covered with gold or silver nanoparticles. These newly synthesised materials have since shown to be effective light-reactive substances that mediate a range of chemical reactions.

Image: Nano-rice particles accumulating on a liquid metal microdroplet surface after ultrasonic processing of the liquid.

14 LOOKING INTO NANOWIRES

Semiconducting nanowires are potential building blocks for various applications including in electronics, optoelectronics, thermo-electrics, and photovoltaics. They can be efficiently produced via a bottom-up growth system known as the vapour-liquid-solid mechanism. Despite considerable investigations into the growth and evolution of these nanowires, the presence of specific atoms and impurities cannot be discerned at the atomic scale using most current techniques.

Recent research by Jiangtao Qu, A/Prof. Rongkun Zheng and colleagues from the University of Sydney (USyd), together with collaborating institutions, mapped the number and 3D position of different types of atoms within a single indium-gallium-arsenic (InGaAs) nanowire, just 50nm in diameter. This was made possible by flagship atom probe tomography (APT) in the AMMRF at USyd. Atom probes are the only types of instrument that can provide this kind of information.

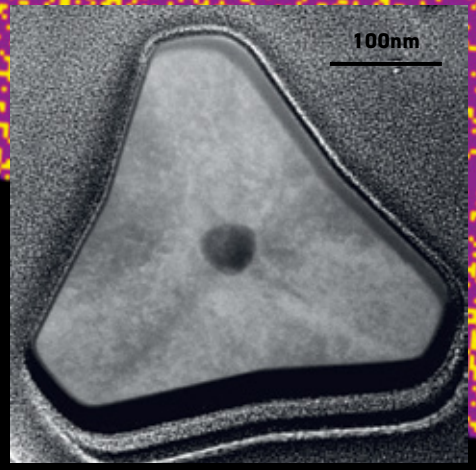
The team also prepared tiny specimens with a focused ion beam that were analysed in the transmission electron microscope. This data formed a basis for the reconstruction of APT data.

Tomography revealed that the core and shell of these nanowires exhibited directional growth and that atoms migrated between the core and the shell of the structure. The team used this insight to propose a new model that explained these atomic-scale 3D observations.

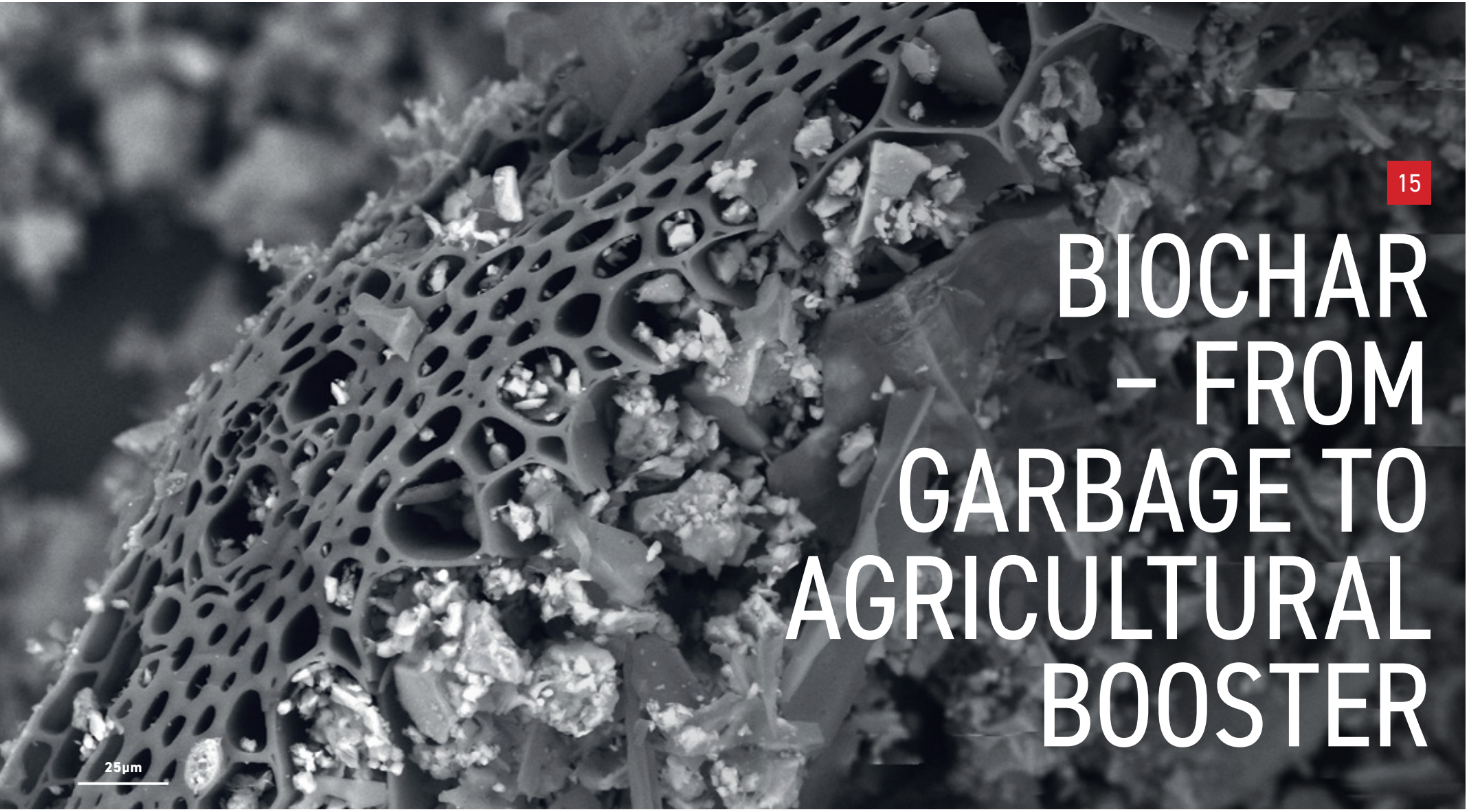
Such unprecedented 3D insights into nanowire structure and shape enable deeper understanding of the relationship between nanowire growth habits, their atomic structure and how these characteristics influence their semiconducting properties. This will help facilitate the development of nanowires for increasingly targeted applications.

Ref. Jiangtao Qu, et al., 2017, Advanced Materials, 29, 1701888.

APT image of a nanowire showing the gallium atoms in yellow and the indium atoms in purple.



TEM image of a nanowire cross-section showing the core-shell structure.



15

BIOCHAR – FROM GARBAGE TO AGRICULTURAL BOOSTER

Image: Highly porous biochar enriched with mineral deposits (lighter coloured particles) impregnating deeply into the pore structure, forming a mineral-organic complex. Sarasadat Taherymoosavi.

INCREASE CROP YIELDS BY UP TO 31% OVER A CROPPING CYCLE

CHALLENGE

Dealing with garbage creates a significant burden in Australian cities. Composting, crushing the waste for use as aggregate, and recycling metals, paper and plastic for reuse, currently ease some of this burden. However turning the remaining waste into a value-added commercial product would make a significant difference. If this could also address the ongoing challenges to the international competitiveness of the agricultural sector, and contribute to carbon management many benefits would be realised.

SOLUTION

Profs Stephen Joseph and Paul Munroe at the University of NSW (UNSW) and their team have tackled this issue by engineering a mineral-rich, commercially viable, biochar from local garbage that can be used as a coating for NPK fertiliser pellets in intensive agriculture. This coating facilitates a range of agricultural outcomes, including enhanced soil nutrient and water retention, stimulated microbial and chemical activity as well as significant carbon sequestration.

To achieve this, PhD students Ben Pace and Sarasadat Taherymoosavi engineered a mineral-rich biochar from first principles, coated a commercial NPK granule and placed it in an Australian wheat-belt soil for several months. From conception to application, their work provided fundamental proof that such a biochar coating could reduce the leaching of nutrients in Australian soils.

The interaction of mineral and organic components in the mineral-rich biochars results in nanoscale variations in mineral composition. These regions become key respiration points for soil microbes, and excellent sites for nutrient and electron exchange with plant roots.

The researchers used scanning and transmission electron microscopy in the AMMRF at UNSW to compare the microstructure of garbage-derived biochar with one composed of harvested wheat-straw and basalt dust. They found that although the microstructures were comparable, more accessible nanoscale minerals were retained in the garbage-derived biochar pores than in the alternative.

IMPACT

A previous collaborative UNSW study of crop productivity found that the replacement of one quarter of the chemical fertilisers in NSW cropping regions with garbage-derived biochar could:

- increase crop yields by up to 31% over a cropping cycle
- reduction in CO_2 emissions from the land by 7%
- decrease NSW agricultural global warming potential by 43%
- recycle half of Sydney's current garbage

This substantially opens the way for repurposing this waste stream into a range of future agricultural products.

Sources: ABS, NSW Government

16 SUPERTHIN METAL OXIDE NANOSHEETS FOR ELECTRONICS

Two-dimensional (2D) materials have fundamentally fascinating properties with a wide variety of potential applications in the electronics industry. Unfortunately most materials do not naturally exist in layered structures making it extremely challenging to prepare atomically thin layers. PhD student Ali Zavabeti, working with Prof. Kourosh Kalantar-zadeh and Dr Torben Daeneke at RMIT University, developed a simple method to prepare ultrathin 2D oxide structures that were inaccessible before. The approach uses nontoxic gallium alloys that are liquid at room temperature. These are used as reaction solvents to dissolve other, more reactive elements.

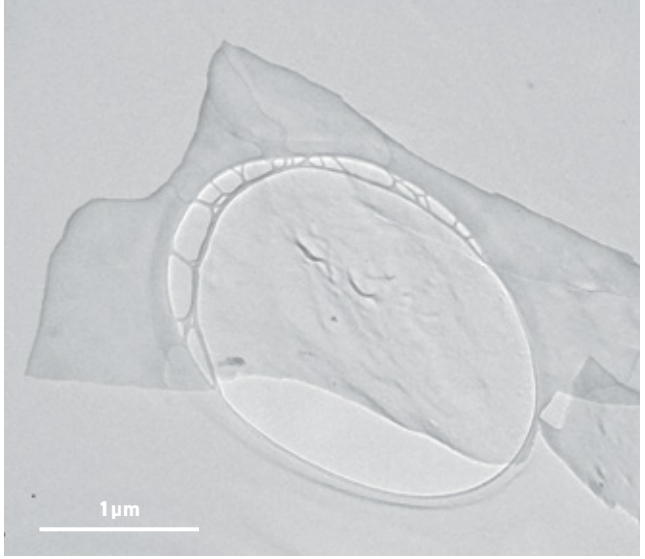
Similar to most metals, liquid metals feature an ultrathin surface oxide – a naturally occurring 2D material. Thermodynamics dictate that the most reactive element within the liquid will move to the surface layer.

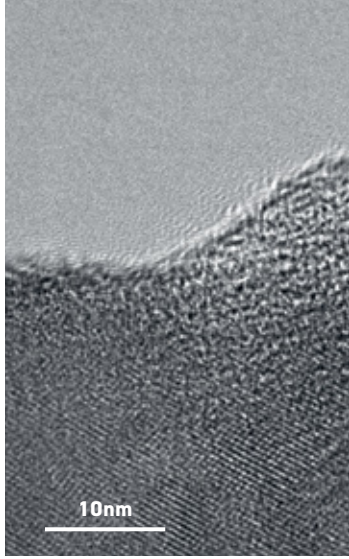
The team developed methods to isolate these surface oxide layers either as printed layers on a substrate, or suspended in a liquid solvent using reactive gas injection. Nanosheets of aluminium, hafnium and gadolinium oxide with layer thicknesses between 0.5 and 1 nanometre, and lateral dimensions of several micrometres were successfully produced. The methods are predicted to be suitable for producing oxide sheets from roughly one third of all elements.

The researchers used the AMMRF linked laboratory at RMIT to identify the materials, determine the crystal structures and conduct band gap analysis of the nanosheets by using X-ray photoelectron spectroscopy and transmission electron microscopy. They have also used scanning electron microscopy to conduct energy-dispersive X-ray spectroscopy to verify that their alloys were homogeneous.

They showed that the 2D oxide layers were of high quality with no defects and excellent dielectric properties, making them ideal for use as insulating layers in electronic components.

Ref. A Zavabeti et al. 2017, Science 358 (6361), 332.

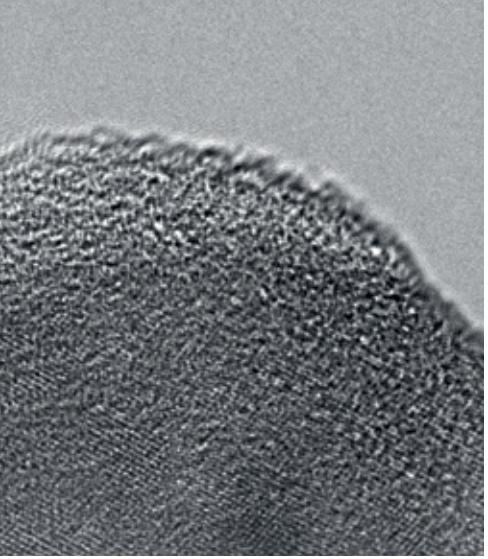




Transmission electron micrographs of a sheet of hafnium oxide.

PUBLISHED IN SCIENCE MAGAZINE

A drop of liquid gallium.

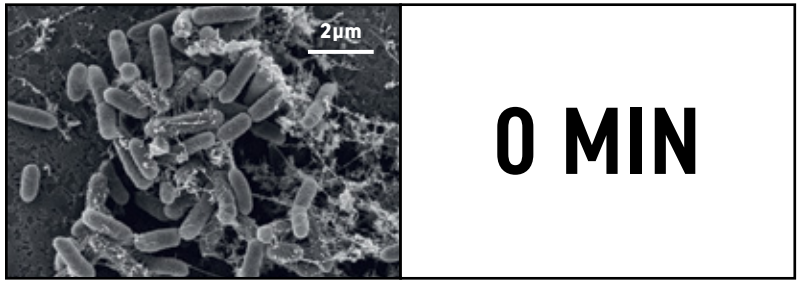


17 NEW WEAPON AGAINST SUPERBUGS

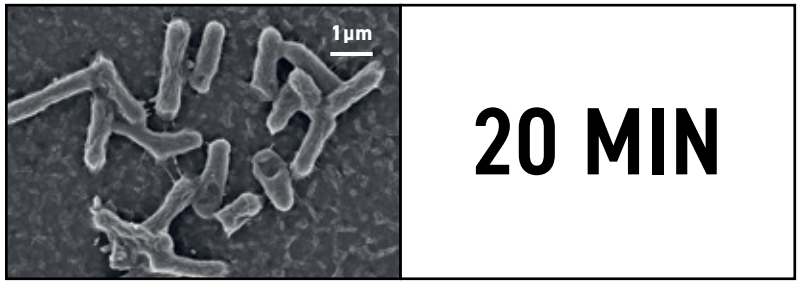
Recce Limited (ASX: RCE) is a pre-clinical-stage pharmaceutical company developing a new class of synthetic antibiotic. New antibiotics are essential to overcome increasing resistance among bacteria. Superbugs could kill 10 million people a year by 2050 – more than cancer kills today.

Recce worked with the AMMRF at the University of Western Australia to capture images of RECCE® 327 destroying the bacteria *Escherichia coli*, the superbug form of which has been declared by the US Centres for Disease Control and Prevention as an urgent threat to world health. The scanning electron microscope images demonstrate the drug's unique mechanism of action, initially weakening the cell walls of the bacteria, then causing cell wall collapse and bacterial cell death within a few hours. This, alongside a variety of other data will support Recce's Investigational New Drug (IND) submission to the US FDA for a Phase I clinical trial for treating blood poisoning from bacteria.

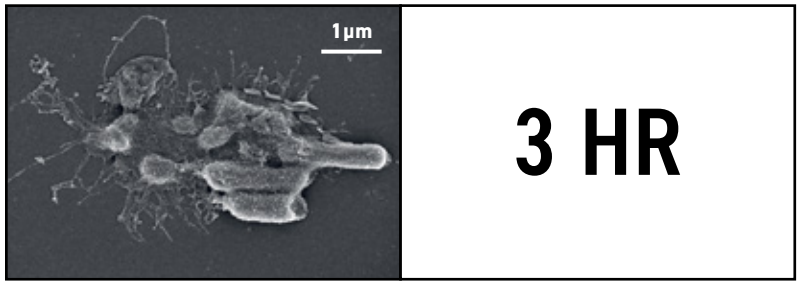
Recce's Executive Chairman Dr Graham Melrose said, "Following on from our January announcement that RECCE® 327 reduces illness in mice infected by resistant *E. coli* bacteria, these images show our lead compound in action. The images reinforce the essential essence of Recce's unique and patented synthetic antibiotic technology to non-selectively attack and weaken the outer membranes of bacteria, which then collapse as a result of release of their internal metabolic pressures. We believe that RECCE® 327 offers great potential as a new class of antibiotic to address the urgent medical need caused by bacteria becoming ever more resistant to the current arsenal of antibiotics."



0 minutes - E. coli cells (oblong shapes) are healthy, smooth and intact



20 minutes – Significant cell membrane weakening and disruption is evident



3 hours – Complete cell breakdown and bacterial death

18 ULTRA-HIGH RESOLUTION ANALYSIS OF BIOMARKER VESICLES

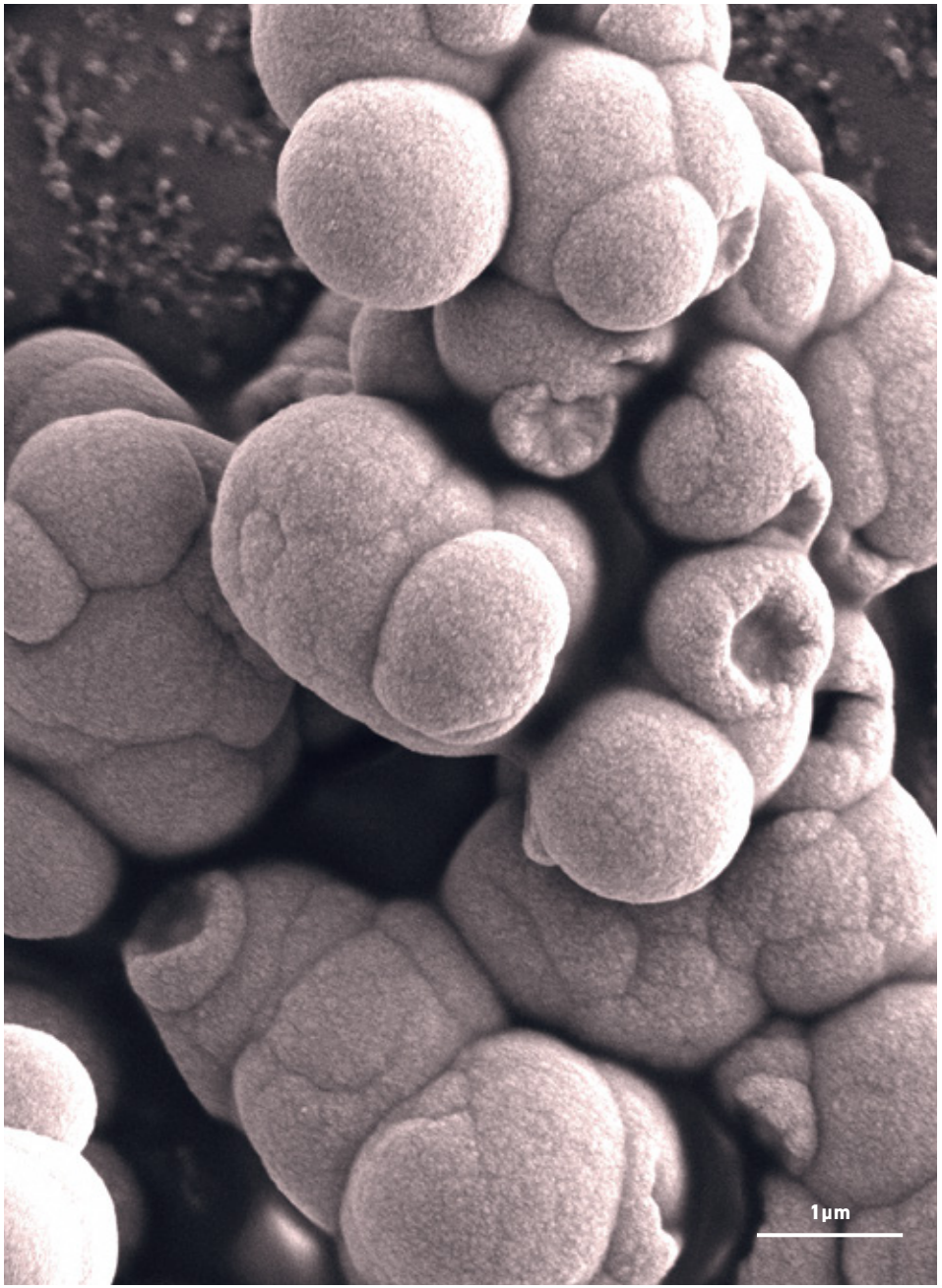
Communication between cells is mediated by the production and export of extracellular vesicles. These highly specialised nanoscale messengers contain fluid that delivers biological signals that ultimately determine cellular function. However, environmental stress or disease can profoundly alter production and composition of these vesicles, which can also carry 'undesirable' messages that contribute to disease. They are therefore researched extensively worldwide as biomarkers for the detection and prognosis of diseases.

Despite the potential of extracellular vesicles as selective biomarkers in medical diagnostics, little is known about their microstructure. Because the vesicles are typically 30-500 nanometres in diameter, transmission electron microscopy is often used to provide adequate resolution when imaging the vesicles. However, TEM sample preparation is tedious and time consuming and the highly sensitive vesicles can lose their structures upon contact with harsh chemicals, at high temperatures or under vacuum.

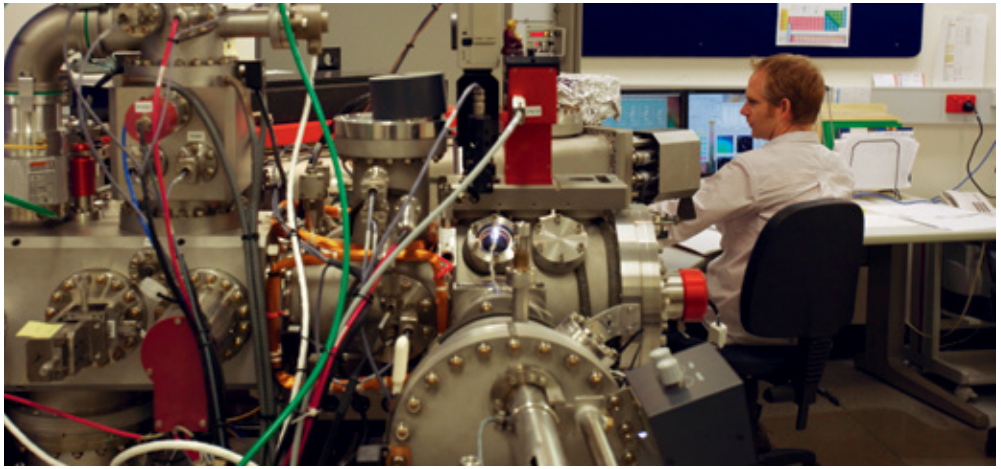
To develop a more efficient imaging method Dr Wojciech Chrzanowski and PhD student Sally Yunsun Kim at the University of Sydney (USyd), together with the AMMRF biological specimen preparation specialist Naveena Gokoolparsadh, developed a unique, innovative method for preparing extracellular vesicles for ultra high resolution scanning electron microscopy (SEM). They used freeze-drying to immobilise the vesicles on polyethylenimine-coated Thermanox™ glass slides. This gave high quality samples that provided excellent resolution in the SEM at the AMMRF's USyd node.

This method proved to be highly successful, with the team obtaining high resolution structural images. Other aspects of this work are the subject of a current patent application.

Image: Scanning electron micrograph of extracellular vesicles after freeze-drying.



19 SUPPORTING INDUSTRY – SILANNA



The AMMRF works with a range of industry partners from family run, small/medium enterprises to global multinationals needing that extra special capability that even their R&D lab capabilities can't fulfill.

The Silanna Group, headquartered in Brisbane, has grown from humble Australian roots to being a key player in power management products in the semiconductor industry globally. Their innovative products set new performance and efficiency benchmarks in a highly competitive industry. Silanna now has offices in Sydney, San Diego, North Carolina and Singapore.

To analyse their semiconductor wafers, Silanna makes use of the AMMRF flagship secondary ion mass spectrometry facility at the University of Western Australia (UWA), one of only a few nanoSIMS labs in the world available to industry. It offers elemental composition analysis capable of detecting less than one part in a million. It also allows nanoscale 3D images to be built providing valuable depth profiling information to inform process engineers.

"Having the AMMRF at the University of Western Australia with their flagship nanoSIMS capability available to Silanna in Australia means a lot to us. We use the capability due to its specialised analysis which we would otherwise likely have to go without. We are also involved with another NCRIS-funded capability, ANFF, and it is unlikely that capabilities like this would be available in Australia without this important commonwealth co-funded support. It's an enabler for world class process manufacturing and development that allows companies like Silanna to operate on home turf." Andrew Brawley, VP Manufacturing, Silanna Group & Board Member, ANFF.

Image: nanoSIMS and flagship engineer at UWA, A/Prof. Matt Kilburn

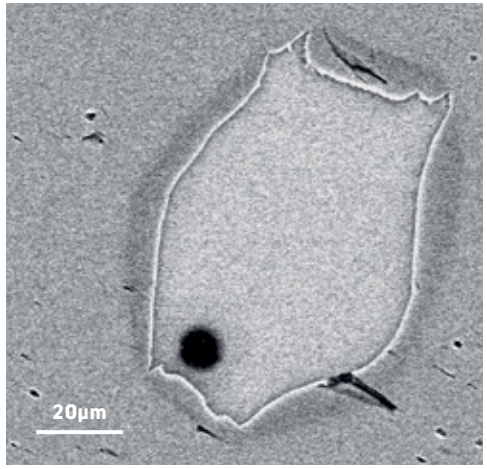
20 HIDDEN CLUES TO ORE FORMATION

Much of the world's mineral wealth is formed as the result of magma transporting metal from deep in the earth. To access this wealth, we need to know how and why certain magmas form and how their composition affects the formation of subsequent mineral deposits. This is challenging, since erupted material typically undergoes dramatic changes as it ascends to the surface, hardly resembling its original composition.

Melt inclusions; microscopic droplets of magma, trapped by crystals growing in magma chambers provide clues about the original magma conditions and composition. However, melt inclusions often continue to crystallise around their edges, preferentially removing certain components. This changes the inclusions' overall composition. By understanding the nature of the preferential crystallisation, scientists can better infer the original chemistry of melt inclusions and make inferences about how valuable metals are transported.

Matthew Valetich, Dr John Mavrogenes and Dr Richard Arculus at the Australian National University (ANU) have done just that in their study of melt inclusions from magmas produced approximately 50 million years ago from two colliding tectonic plates, south of modern Japan. They used a combination of scanning electron microscopy, X-ray mapping, quantitative X-ray microanalysis and laser ablation inductively coupled plasma mass spectrometry, all available in the AMMRF at ANU.

Their analyses show that peripheral crystallisation can change the volume of melt inclusions by over 25%, affecting the chemistry significantly. This work enables better and more accurate recalculations of the original melt composition and this methodology enables direct measurements of otherwise unpreserved magmas and underpins our understanding of magmatic ore body formation.



A large melt inclusion inside a surrounding crystal. The inwardly concaved, uneven edges of the melt indicate significant overgrowth of the surrounding crystal since the entrapment of the melt inclusion. The melt inclusion would have formed a more oval shape.

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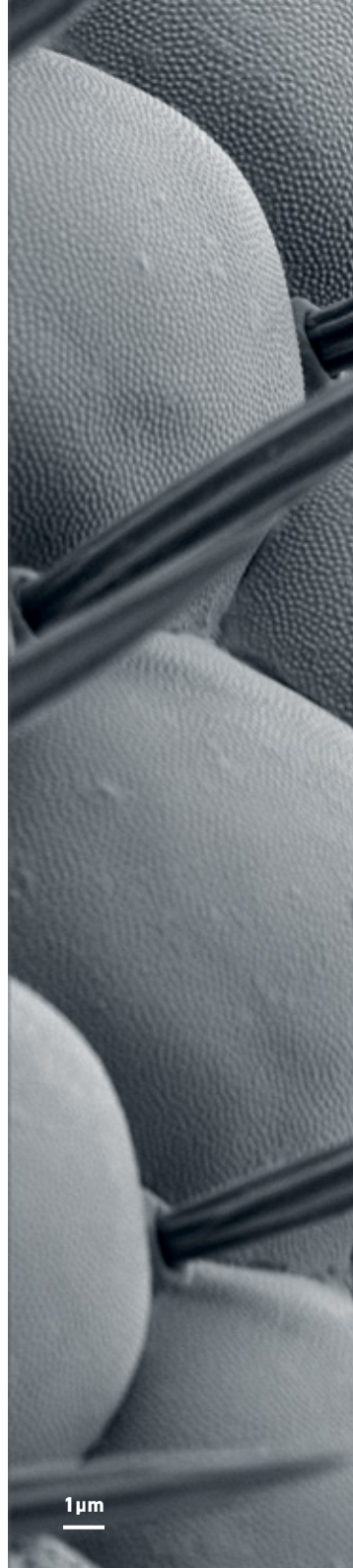
Image.
Scanning Electron Micrograph of an Ant Eye.
Delfine Cheng and Errin Johnson



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