ammrf
Australian Microscopy
& Microanalysis Research Facility

essential for australia

PROFILE 2015

FOUNDING NODES

SOUTH AUSTRALIAN REGIONAL FACILITY (SARF)

Our vision

The AMMRF is Australia's peak research facility for the characterisation of materials through macro, meso, nano and atomic length scales by means of advanced microscopy and microanalysis.

Our mission

The AMMRF is a user-focused, interdisciplinary organisation that employs microscopy and microanalysis to explore structure–function relationships of materials in the physical, chemical and biological sciences and their technologies.

Accessible to all Australian researchers, the facility provides a quality user experience enabled through the provision of world-class research services, research training and research programs.

FUNDED BY

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from the minister

Around the world, research plays a crucial role in the conservation, dissemination, and advancement of knowledge. Research drives innovation, and is vital to Australia's future economic prosperity. In that regard, our nation is well placed for the century that lies ahead.

Initiatives such as the National Collaborative Research Infrastructure Strategy (NCRIS) deliver world-class research facilities so that Australian researchers can explore and solve complex problems, both here and around the globe.

NCRIS facilitates strong partnerships between the research sector, business, industry and government to support world-class research. These linkages are critical if we are to realise the full benefits of our research breakthroughs.

The Australian Microscopy & Microanalysis Research Facility is an essential part of our national research effort, helping us to find solutions across a wide variety of fields. The Australian Government is pleased to support important research facilities such as the AMMRF through NCRIS.

Senator the Hon. Simon Birmingham

Minister for Education and Training

from the chair

At the beginning of 2015, the AMMRF faced uncertainty concerning the continuation of the Federal Government's NCRIS program. Subsequently, the AMMRF board was very encouraged when the Federal government determined to extend support of Australia's national research infrastructure out to mid 2017.

During the year, the AMMRF's foundation CEO, Prof. Simon Ringer, was promoted to commence a new role at the University of Sydney. Dr Miles Apperley, the AMMRF's former COO, succeeded Simon, becoming the AMMRF's new CEO. Miles brings to this role an extensive knowledge and experience of the facility's operations, combined with a clear vision for the future of the AMMRF. The board anticipates that this knowhow will steer the organisation in its transition beyond its now mature sustainable establishment towards a new phase of research and technology-driven capability growth for the future.

The AMMRF is very well placed to further its strategies to continually improve the delivery of its core services, while building international connections and growing its engagement with industry; all of which support the Australian Government's Competitiveness Agenda.

Among all the projects registered within the AMMRF's nodes during the 2014-2015 financial year, almost 20% are supported by industry. This endeavour includes direct relationships with professional or research staff in one or more of the AMMRF's laboratories or, as less direct involvements, where an industry partner is collaborating with an academic researcher who is using an AMMRF facility to provide the microscopy needed for that industry-backed project. The AMMRF believes that this level of industry support and engagement is contributing to the vision recently articulated by Prime Minister Turnbull in which he has challenged Australia to become a more agile, innovative and creative nation.

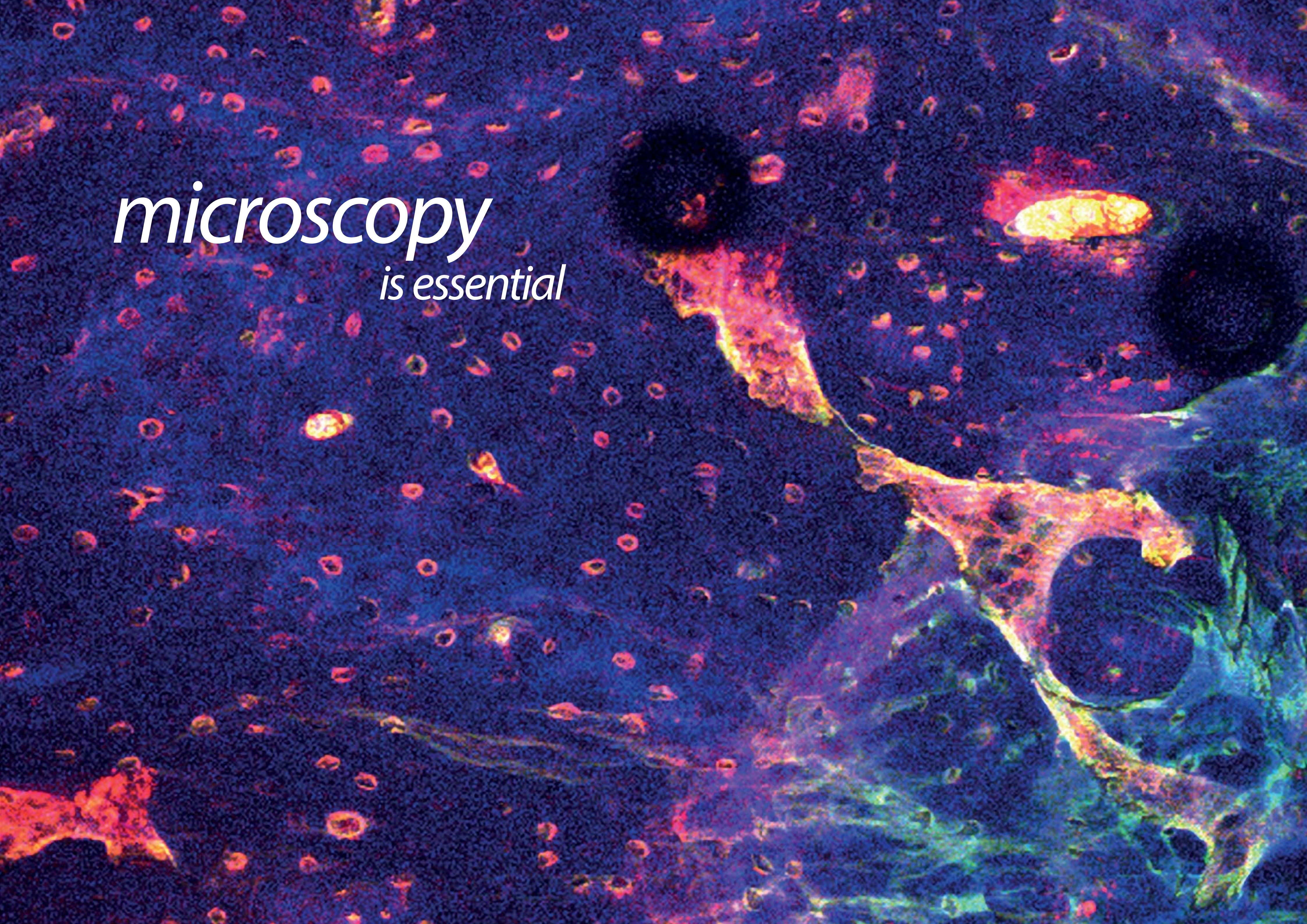
Dr Gregory R. Smith
Chair of Board

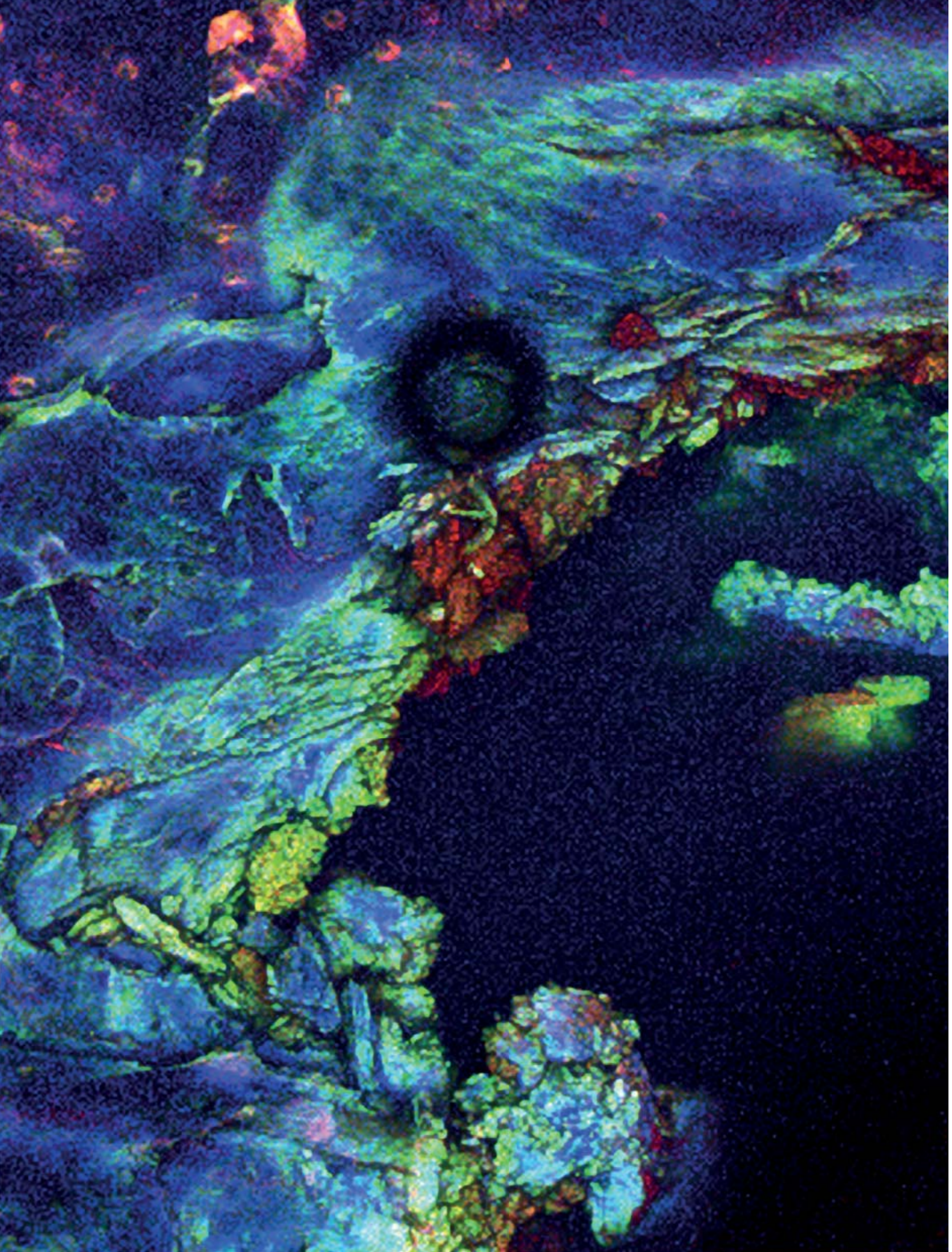
from the ceo

The theme of the 2015 Profile is Essential to Australia. Microscopy and microanalysis are very powerful tools for scientific discovery, which ultimately impact the health of our population; lead to innovation, technological advances and new industries; sustain our environment and better use, and even reuse, our natural resources. Our research infrastructure delivers these tools in a way that adds considerable value to the basic hardware. Our access, expertise, training, support and online tools are all underpinned by our collaborative research infrastructure. In the same way that transport networks, hospitals, education, communication, industrial and urban infrastructure underpin the economic activity and development we enjoy in Australia, so does research infrastructure.

The Profile once again highlights some of the scientific outcomes and social impacts enabled through the availability of our world-class microscopy and microanalysis infrastructure. A new scientific discovery is a starting point but our work does not stop there. The expertise and instruments in our facilities enable new knowledge to be created. This in turn converts discoveries into opportunities, builds new businesses, improves existing products and processes, helps heal and extend life, manages the useful life of existing structures, understand ancient civilisations and probe the origins of the earth and solar system. Scientists and engineers need our research infrastructure and they need it to be world-class.

Dr Miles Apperley
Chief Executive Officer


microscopy
is essential



ammrf
Australian Microscopy
& Microanalysis Research Facility

For so much of Australia's great research, and the innovation that flows from it, microscopy is essential.

Our collaborative facility provides microscopy in an environment of expertise and support, adding value to our world-class instruments.

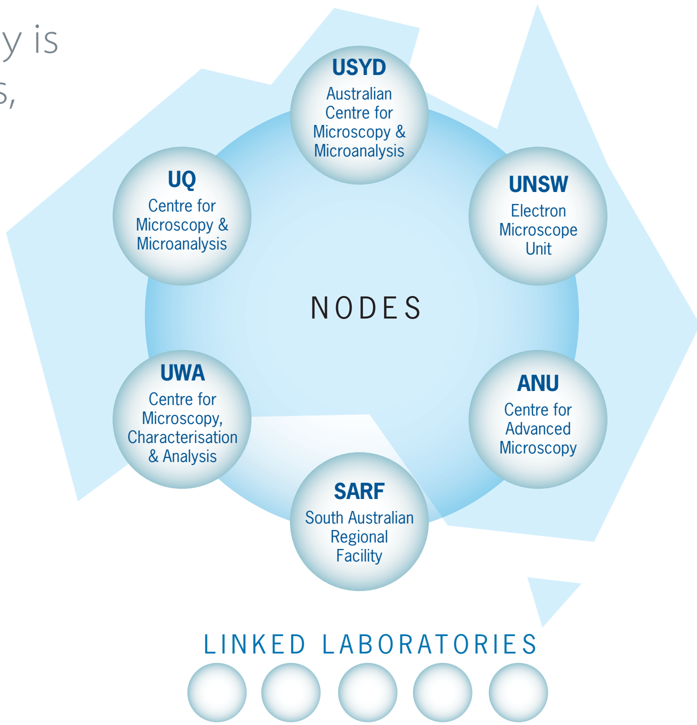
Over 200 instruments are run by our expert staff. Together we support researchers to achieve meaningful discoveries that address important challenges.

collaboration: *efficiency*

The Australian Microscopy & Microanalysis Research Facility is a national grid of instruments, expertise and online tools dedicated to nanostructural characterisation.

Major university-based centres are the core nodes of the network, collaborating to make efficient use of sophisticated, distributed capability.

We enable discovery and innovation in fields such as engineering, agriculture, healthcare and geoscience. Our facility complements other national research infrastructure to contribute significantly to Australia's wellbeing and economic growth.



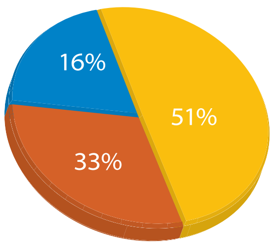
Data and informatics along with education and training are two of our priority areas. Expert groups from around the facility are actively developing and implementing our strategy.

2014–15 in figures

USERS

Total: 3,196

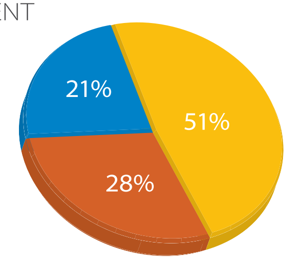
By discipline:



INSTRUMENT HOURS

Total: 240,498

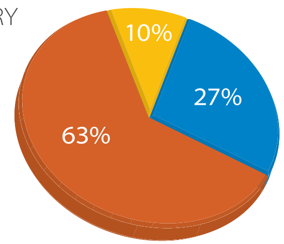
By discipline:



- Physical/Materials Science
- Biological/Medical Science
- Environmental Science/Geoscience

USERS FROM INDUSTRY

By sector:



- Manufacturing
- Biomedical
- Environmental/Resources

3,000

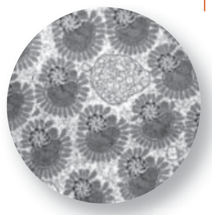
researchers each year

advanced microscopy

Access to our specialised microscopy and microanalysis is available on the basis of merit to all Australian researchers. We respond to user demand, regularly updating the techniques we offer.

Our collaborative structure enabled a suite of flagship instruments to be established, many of which are unique in Australia. Dedicated flagship engineers run these instruments, offering an extensive range of specialised techniques. The collaborative structure maximises efficiency and productivity.

Research outcomes from flagships are highlighted in our research stories by the icon above.

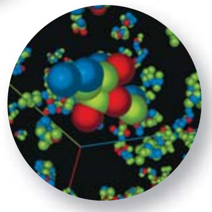


Transmission Electron Microscopy

Imaging & Analytical Spectroscopy
Cryo-Techniques & Tomography
Phase & Z-contrast Imaging
Electron Diffraction

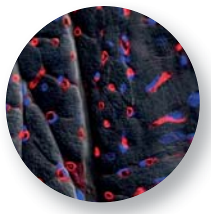
Specimen Preparation

Biological & Materials
Cell Culturing & Molecular Preparation
Thermomechanical Processing
Ion Milling & Machining
Ion Implantation



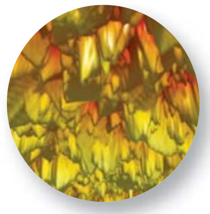
Ion & Spectroscopy Platforms

Nanoscale Mass Spectroscopy
Atom Probe Tomography
Nuclear Magnetic Resonance



Light & Laser Optics

Confocal, Fluorescence & Optical Microscopy
Flow Cytometry & Cell Sorting
Live-cell Imaging
Vibrational & Laser Spectroscopy
Laser Microdissection

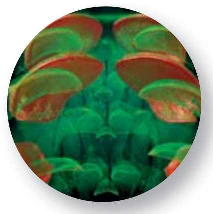


Scanned Probe Techniques

Atomic Force Microscopy
Scanning Tunneling Microscopy
Near-field Scanning Optical Microscopy

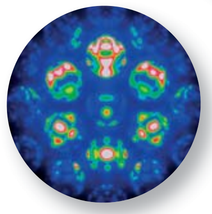
Scanning Electron Microscopy

Imaging & Analytical Spectroscopy
In-situ Imaging & Testing
Cathodoluminescence
Electron Backscatter Diffraction



X-ray Technologies

X-ray Diffraction
X-ray Fluorescence
X-ray Micro- and Nanotomography



Visualisation & Simulation

Computed Spectroscopy
Computed Diffraction
Image Simulation & Analysis
Data Mining

online *tools*

Our suite of online tools support scientific research and training around the world. In readiness for the next phase of their development we have strengthened MyScope and TechFi branding.

TechFi™ enables researchers to quickly identify relevant microscopy techniques to address their experimental questions.

The user-friendly interface presents technique options based on choices from a list of biological or physical experimental types. It matches researchers with the location of the relevant instruments and expertise they need to get started. This feeds neatly into MyScope where they can begin their training. TechFi is also being used for a wide range of teaching applications.

MyScope™ is a comprehensive online training environment to prepare researchers for their initial training on our instruments. This improves efficiency by freeing up instruments for experienced microscopy users to conduct their research.

The success and popularity of MyScope have led us to develop our Corporate Partnership Program as a means to raise funds for further development of MyScope. FEI Company is the first to come on board as our MyScope Outreach Partner. Together we are developing an online microscopy education and outreach module that will enable people to discover the unseen world at the heart of the natural world and many everyday technologies.

science outreach

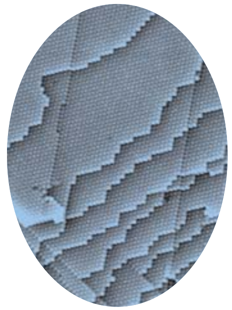
STEM engagement and education is an increasing priority in advanced economies.

Eye-popping microscopy images wowed the crowds at the Adelaide Festival with micrographs created in our Adelaide labs for artist Jessica Lloyd-Jones projected onto the Adelaide Festival Centre roof as part of the *Blinc* exhibition.

Our touring exhibition of microscopy images, movies and sculptures, Incredible Inner Space, has been supporting science, technology, engineering and maths (STEM) engagement since 2011. The beauty and intriguing patterns and shapes of the unseen world are an enticing gateway to science.

Our exhibition is currently on show at the Oregon Museum of Science and Industry, taking Australian science to an international audience.

Opals were the focus for a stunning exhibition at the South Australian Museum.



Our Adelaide microscopists provided images of precious and potch opals, revealing the structural basis of the fiery colours that make opals so attractive and intriguing. The colour of opals comes from their nanostructure rather than their chemistry.

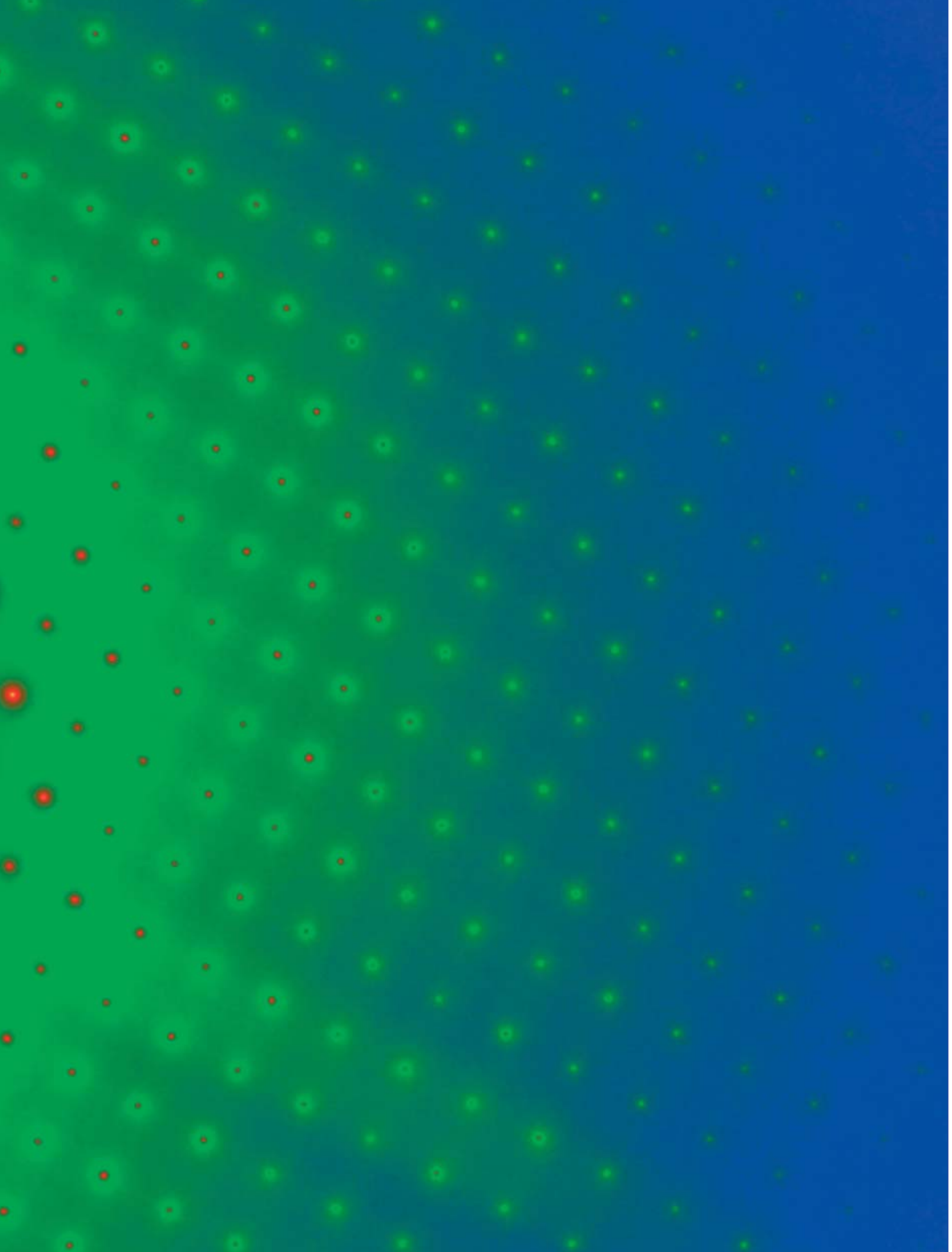
A 3D-printed chiton tongue is one of the display highlights at the Discovery Centre of the Sydney Institute of Marine Science.

The chiton is a marine mollusc that scrapes algae off rocks using its iron-reinforced tongue. The 3D print was created from Dr Jeremy Shaw's X-ray microtomography data collected in the AMMRF at the University of Western Australia. The printed object is many times the size of the real specimen allowing visitors to handle it and explore the amazing details of the complex natural structure.

sims sydney institute of marine science

discovery

& innovation



A strong innovation sector brings economic growth through new industries and exciting technologies.

SMEs and large companies alike can access our microscopy infrastructure to add value to their processes.

Engagement encompasses fast turn-around testing services as well as long-term strategic R&D. Some of these long-term industry partnerships, such as ARC Linkage Projects, are featured in our research stories, aligning to the government's Industry Growth Centres Initiative.

what we do

powerful instruments

world-leading experts

international benchmarking

technique development

new analysis methods

efficient training

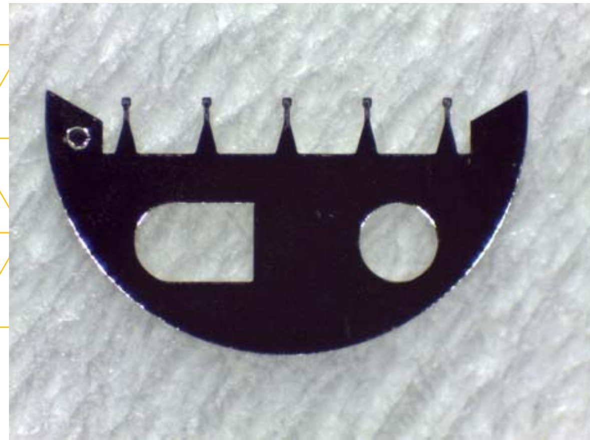
popular online tools

dedicated user support

Selected patents enabled by the AMMRF

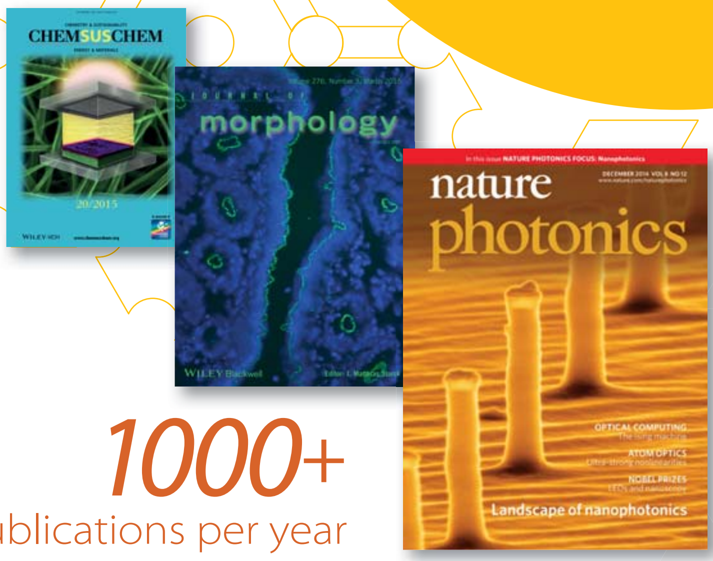
- Elastic Hydrogel – US20150274805
- Anti-biofilm polymer WO/2015/139079
- Process for preparing a polymer WO/2015/113114
- Scratch resistant polymers – PCT/AU2014/050062
- Abalone hemocyanin protein as an antiviral – 2014904790
- Developments in biomedical implantable materials – 2015900703
- Improved thin film tube reactor - 2015902207
- Compositions and methods for extracting components from proteinaceous substrates – 2014903314
- Materials and processes for removing copper from solution - 2015900242
- Antibiofouling and/or antiscaling coatings – 2015902087

Microscopy spin-off enterprise



Spin-off company, Microscopy Supplies Australia, licenses technology developed in the AMMRF at the University of Sydney to manufacture and distribute low-cost holders and supports for TEM and atom probe microscopy. This is innovation making advanced microscopy more efficient.

www.microscopysuppliesaustralia.com



1000+
publications per year

Increasing numbers of papers published by our users in the top peer-reviewed scientific journals can be attributed to sustained strategic investment in microscopy & microanalysis infrastructure.

innovation pathways

microscopy enables innovation…

…from product development stages, to longterm strategic R&D

discovery

Researchers at Flinders University have developed a new mercury-binding polysulphide chemical made from industrial waste. It is patented and could be used for environmental remediation. Commercialisation is now underway. Read more on p21.

commercialisation

All of these examples have relied on AMMRF microscopy

HazerGroup

Hazer Group was established in 2010 from technology developed at the University of Western Australia, to produce clean hydrogen and high-grade synthetic graphite from natural gas and iron ore. Hazer Group is currently selling shares to raise $5M to enable commercialisation of their breakthrough technology.

elastagen

University of Sydney spin-off company Elastagen won a $1M Wellcome Trust Translation Award to fast-track elastin mesh to clinical trials for wound healing.

Nano-Nouvelle innovative materials technology

University of Queensland (UQ) spin-off company Nano-Nouvelle closed a $3.7 million financing deal to support continued development and commercialisation of its novel battery electrode materials.

TENASITECH

UQ spin-off compnay TenasiTech has developed SOLID-TT™, an additive to help acrylic glass withstand scratching and maintain its glossy appearance. They were a finalist in the 2015 Telstra Business Awards for Queensland. They also received $509,000 to complete the marketing phase of their commercialisation.

small to medium size businesses

"We approached the AMMRF at Sydney University to do some microscopy on a product of ours. The product has a surface coating not visible by the naked eye. The microscopy helped us in two ways. We could compare our product's functional quality against competitors' products and we use the microscopy results as confirmation of the manufacture quality, which could not be seen by eye. The high-quality microscopy images will also be used by our graphic designers for product information material and marketing prints. Their staff were great to deal with, informative and helpful."

Paul English
Product Design Manager,
VGM International Pty Ltd

"Bambury is at the forefront of bedding technology. Mite-Guard is one of the longest running ranges for the company and is recommended by allergy and asthma specialists. It features a specially developed micron dust filter membrane sandwiched between two layers of fabric, allowing barrier protection against allergens whilst remaining breathable for comfort. Given the product has inherent health benefits, it was essential we backed up our claims and had full confidence in our product. The AMMRF at UWA provided the highest quality imaging - far superior to what we had seen from other microscopy services. Previous laboratory tests proved the product worked by not allowing microscopic particles to pass through the fabric, but with the AMMRF we were actually able to see the fabric up close at 2000x magnification, proving the fibres of the filter membrane are packed so tightly together that harmful allergens are not able to pass through. AMMRF's open communications, fast turnaround times and professionalism also made our experience a real pleasure."

Ray Chiu
Product Development, Bambury

large companies

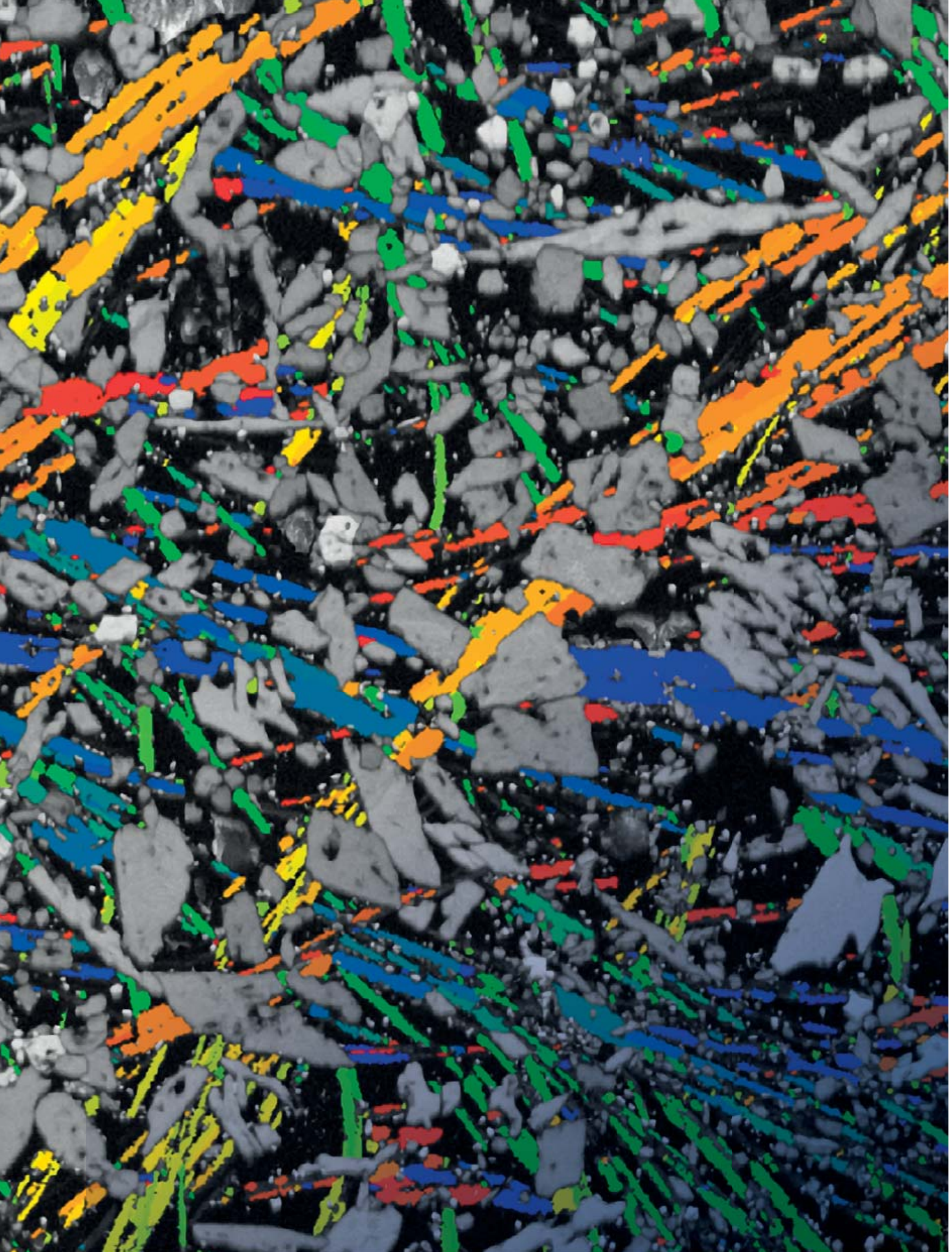
Procter & Gamble

To help Procter and Gamble develop better shampoo, the AMMRF at UWA provides unique high-resolution NanoSIMS analysis of the penetration of specific molecules into hair.

Weir Minerals

Through an ARC Linkage Project, Weir Minerals access sophisticated microscopy in the AMMRF at the University of Sydney to develop new super-tough alloys to give their mining machinery a competitive edge.

enabling world-class research



ammrf
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Our instrumentation and expertise extend the range of inspirational and world-class research outcomes from Australian science.

This section illustrates how the research we support is contributing to finding solutions to global challenges. Their alignment to Australia's Strategic Science and Research Priorities is indicated by these icons:

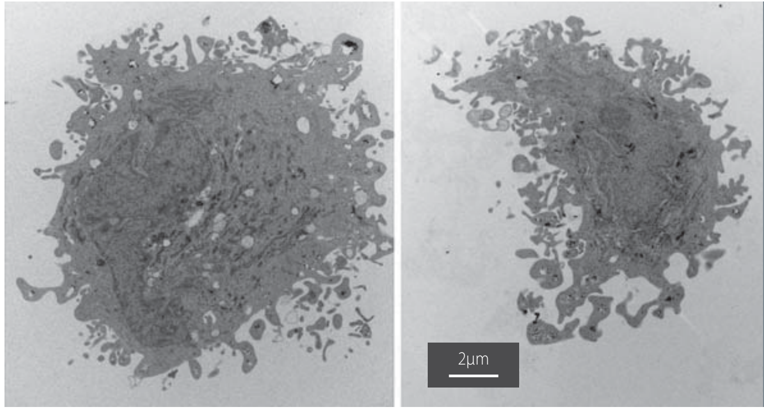
Energy & Resources
Transport
Manufacturing
Food
Health
Soil & Water
Environmental Change

DENTAL PULP STEM CELLS FOR TREATING STROKE

Stroke is the leading cause of adult disability in Australia. Current therapies usually target the acute phase rather than the remaining disability. Stem cell based therapies are potential treatments for a number of diseases including stroke. Dental pulp stem cells (DPSC) in particular, could provide a readily accessible source of stem cells as many people now retain their teeth into older age. This would allow autologous (self/self) transplantation following a stroke to improve functional outcomes.

In our 2012 Profile we reported on Dr Karlea Kremer's research in this area. She showed that rodents whose brains were injected with DPSCs following a stroke showed significantly improved limb function. Dr Kremer, now at the South Australian Health and Medical Research Institute is looking to the future application of these cells in human patients who have suffered a stroke. As stroke affects many older people, she is now investigating whether DPSCs obtained from older patients have the same properties and function in the same way as those from younger patients. She has been using the AMMRF at the University of Adelaide to look at the fine detail of the cells' structure by using transmission electron microscopy. DPSCs from different age groups showed no obvious structural differences. All the cells showed well-defined, irregularly shaped nuclei, endoplasmic reticulum and membrane projections on the outer membrane. Electron microscopy is combining with functional data to provide a thorough comparison of the different-aged stem cells.

Together they are helping to bring stroke treatment with a patient's own stem cells a step closer.



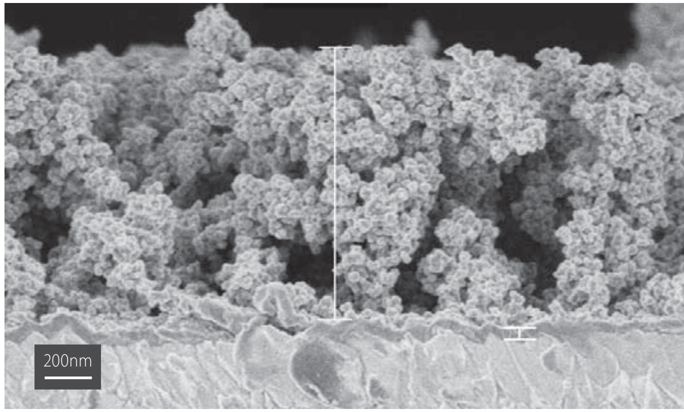
TEM images of DPSCs from a 15 yr old (left) and a 69 yr old (right)

PEROVSKITE SOLAR CELLS ON THE RISE

Perovskite solar cells have been generating a tremendous amount of excitement over the past few years. They are made from an entirely new class of materials and efficiencies have risen faster than for any other type of solar cell to date. One of the components of perovskite solar cells is a porous layer of titanium dioxide; a widely used material found in sunscreen and toothpaste. In solar cells the purpose of the titanium dioxide is to allow electrons to travel in only one direction.

A/Prof. Kylie Catchpole's and Dr Antonio Tricoli's research groups at the Australian National University (ANU) use a new process called flame spray pyrolysis to deposit the titanium dioxide onto the underlying glass substrate. This results in a highly porous titanium dioxide coating with a large surface area. The research team used the AMMRF at ANU for scanning electron microscopy and elemental analysis to see the structure and composition of each layer of the solar cell.

Energy capture efficiencies of about 14% have been reached with their initial samples. This is comparable to perovskite cells produced with the standard process. Importantly with the new process, the titanium dioxide layer can be deposited in seconds. This is an important consideration for fabrication on an industrial scale. The success of the flame-spray-pyrolysis process provides a strong base for future work to further optimise the coating process and test it with different materials that may also allow the energy capture efficiency to increase. This will have the potential to make cheaper solar cells that can produce more power for a given area.



Scanning electron micrograph of titanium dioxide fabricated with flame spray pyrolysis, used for making perovskite solar cells.

essential: greener buildings

CHALLENGE

Energy savings in buildings are highly dependent on the materials. While glass is an attractive option on many levels, it is a very poor insulator, transmitting a great deal of heat. Traditional gas-filled double glazing has a number of problems; it requires special framing, has a thick profile, and a limited service life. A more efficient form of insulated glazing would improve the energy efficiency of buildings.

SOLUTION

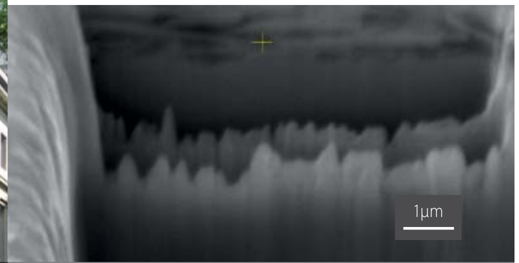
Research started on vacuum-insulating glazing (VIG) technology at the University of Sydney (UoS) over 30 years ago. In the mid 1990s it was licensed to Nippon Sheet Glass (NSG) – now known as the Pilkington/NSG Group. From 2000 the product became commercially available as Pilkington Spacia™, the world's first commercially available vacuum glazing. It has a thermal conductance approximately one quarter that of a single pane of ordinary glass. Its thermal performance is independent of the size of the space between the two sheets of glass, making the VIG much thinner than existing gas-filled insulating units. This makes it a very versatile technology for the construction industry. The VIG unit is constructed from two panes of glass, maintained at a sub-millimetre separation using an array of high strength metal, ceramic or glass spacers. The two panes are joined around the edges with a rigid bond formed using a uniquely formulated glass frit solder. The space between the panes is evacuated to a very low pressure, and this vacuum gap provides the excellent thermal insulation.

R&D continues through industry partnerships including an ARC Linkage Project, helping UoS test new materials and processes for improvements in the next-generation VIG units. Prof. Marcela Bilek and Dr Cenk Kocer now lead the project, using the AMMRF at UoS to look into the composition and structure of VIG materials.

IMPACT

The VIG's lower weight and thin profile:

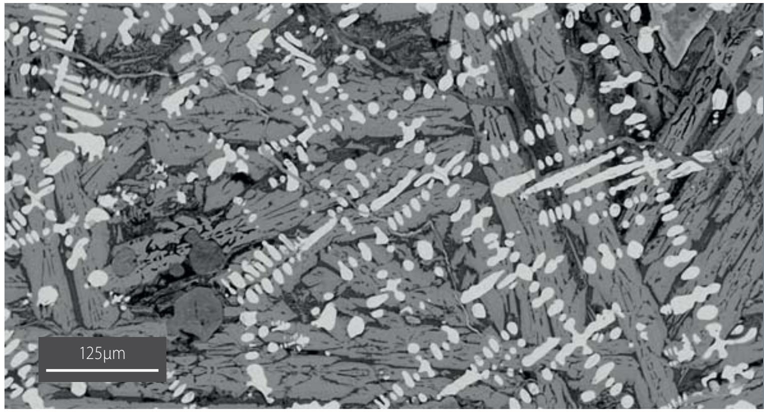
- opens up the retro-fit market to energy-efficient windows, such as in this heritage building at MIT: conventional insulating windows would have required replacement of the original window frames
- has public transport window and fridge door applications



This long-term industry partnership continues to add value to successful commercial products. VIG units provide attractive glazing solutions for commercial, residential and historical buildings, reducing energy consumption and greenhouse gas emissions. Studies have shown that use of insulating windows in Sydney's climate can make houses comfortable all year round, without additional heating and cooling systems.

ANCIENT GREEK SLAGS OF ZAGORA

Zagora is a complete, undisturbed Early Iron Age Aegean settlement from the 9th-8th centuries BC. Archaeological survey and excavation at the site has found an abundance of metallurgical slag, waste material from the metalworking industry. Iron production occurred in Greece for a century or two before the occupation of the site but limited work has been done on Greek metalworking from this period.



Scanning electron micrograph showing the fayalite (mid grey) and wustite (light grey) crystals in a piece of smithing slag.

Ms Ivana Vetta, a postgraduate student at the University of Sydney (UoS) is using scanning electron microscopy coupled with elemental and crystal orientation analyses in the AMMRF at the UoS to uncover the unique microstructure of the slag. This in turn provides information about the pyrotechnological skills and processes used by the ancient smiths.

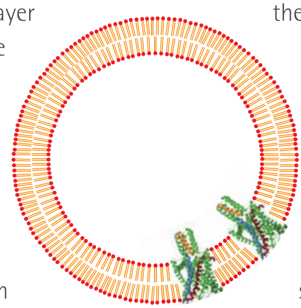
From the outside, the slag appears simply as a lump of mildly magnetic rock but inside the structures are highly variable and contain a complex mixture of iron-rich minerals. The presence and structure of the minerals fayalite and wustite in the Zagora slags indicates that the slags are most likely to have come from the iron smithing phase. It also reveals that a lot of iron was lost in the slag, indicating a very inefficient process for iron production at this stage of history. Analysis also revealed the presence of quartz and silicate minerals, suggesting that sand may have been used as a flux to help purify the iron prior to smithing.

Ms Vetta's results are combining with other archaeological evidence to uncover ancient metalworking processes and how they connect to the wider civilisation.

Ms Vetta acknowledges the permission of the Hellenic Ministry of Culture under the Aegis of the Australian Archaeological Institute at Athens (AAIA).

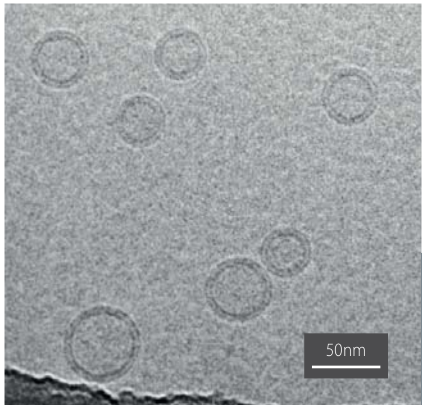
DELIVERING TOXIC DRUGS : NANOSCALE SOLUTIONS

The delivery of toxic drugs for therapeutic benefit, such as in cancer chemotherapy and some anti-fungal and pain-relief treatments, is increasingly being accomplished using nanoscale liposomes. These are roughly spherical nanoparticles with a water-filled central cavity surrounded by an impermeable outer layer of lipids. Encapsulating the drug in a liposome prevents accumulation in non-target tissues as it travels around the body, reducing undesirable side effects. However, the problem is then how to trigger release of the drug from the nanoparticle once it gets to its destination.



A team led by Dr Michael Landsberg from the University of Queensland (UQ) and Prof. Boris Martinac from the Victor Chang Cardiac Research Institute have been developing prototype liposomal drug delivery systems that incorporate specialised bacterial proteins that could act as triggerable nanovalves. The nanovalves are embedded within the lipid layer and when activated will open a pore, releasing the drug. The team use high-resolution cryo-transmission electron microscopy (TEM) in the AMMRF at UQ to visualise their liposomes and investigate the factors influencing the efficiency of drug release. They found that the size of the liposome is significant, an important observation since liposomal formulations often contain a mixture of sizes. They are currently using TEM to evaluate new methods that produce more uniformly sized formulations. Lipid composition of the membranes also appears to influence the size of the liposomes and the cargo release efficiency.

A major focus of future work is on developing mechanisms that can be used safely in the body to trigger opening of the nanovalves.



Cryo-TEM image of liposomes and an illustration showing how the nanovalves sit in the lipid bilayer.

essential: decontamination

CHALLENGE

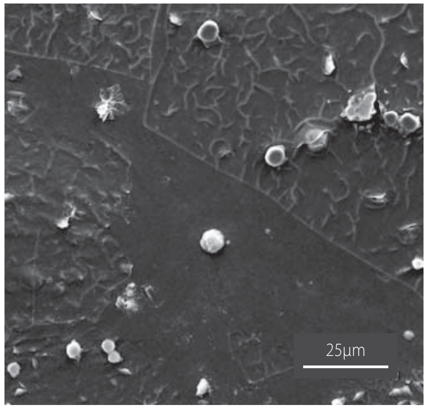
Inorganic mercury and other toxic metals from mining and smelting operations, energy production and industrial effluent contaminate water and soil in many parts of the world. Contamination is very dangerous to human health, food security and the environment. Cost-efficient remediation of contaminated sites is a priority.

SOLUTION

Dr Justin Chalker and colleagues at Flinders University (FU) and the Universities of Tulsa, Lisbon and Cambridge, have invented a new polymer that is easily made just from sulfur and limonene, industrial by-products of the petroleum and citrus industries. This unusual polysulfide has a high affinity for metals such as mercury, so is useful for removing toxic mercury salts from contaminated water and soil. The researchers also found that it undergoes a selective colour change from dark red to yellow when mercury binds to it. This colour change only occurs with mercury, so the polysulfide is effectively a selective sensor. The polysulfide also binds to palladium and removes it from water. This would enable the recovery of valuable palladium catalysts, widely used in the chemical industry.

The team elucidated the metal-binding process through a combination of Raman, scanning electron microscopy (SEM), and elemental analysis (EDS) in the AMMRF at FU. EDS experiments revealed that micro and nanoscale particles of mercury sulfide formed and adhered to the polymer (SEM image on the right).

The new polysulfide is not toxic and can remove mercury safely from complex mixtures such as river water and pond sediment. With a patent and multiple provisional patent applications filed, FU and the University of Tulsa have partnered to pursue commercialisation of this environmental remediation technology.



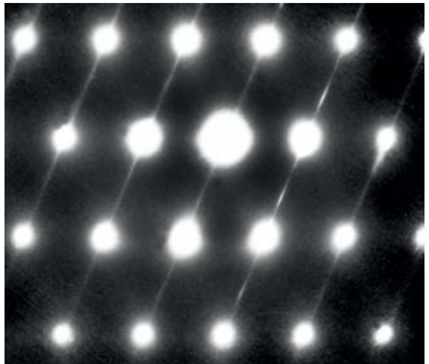
IMPACT

From the 70M tons of waste sulfur and 70, 000 tons of limonene produced annually, the new, non-toxic polysulfide can be synthesised on a large scale, for cost-effective:

- removal of mercury and other heavy metals from the environment
- mercury sensing
- recovery of useful heavy-metal catalysts

NEXT GENERATION ENERGY STORAGE DEVICES

Designing better materials for next generation capacitors can enable the miniaturisation of components, enhance device performance and enable solid-state energy storage. The ideal materials (called dielectrics) should have high energy-storage capacity, low energy leakage and good temperature stability. Unfortunately, it is extremely difficult to obtain all three properties simultaneously. However, Prof. Ray Withers and Future Fellow Prof. Yun Liu's group at the Australian National University (ANU) has recently designed such a material; titanium dioxide incorporating low levels of aluminium and niobium.



Electron diffraction pattern of the new material.

Their successful material design has strongly relied on an understanding of the distribution of the aluminium and niobium ions within the material and the effect this has on surrounding atoms. The researchers have used transmission electron microscopy (TEM) and electron diffraction in the AMMRF at ANU to investigate the detailed arrangement of atoms. The results provide an understanding of how the extra ions affect the structure and behaviour of the new dielectric materials.

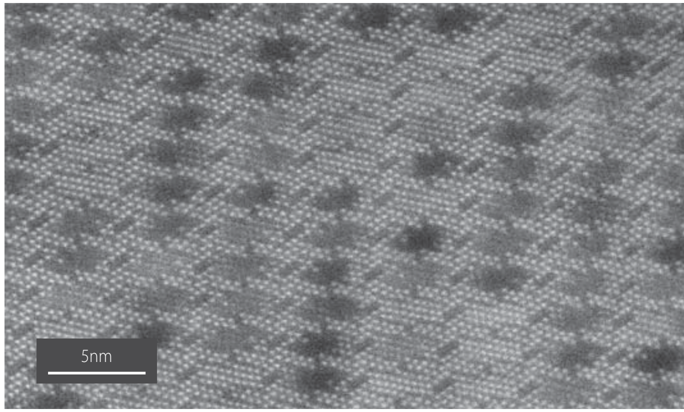
Electron diffraction shows that the aluminium atoms are distributed at specific positions between the regular arrangement of titanium and oxygen atoms in the crystal. This disrupts the long-range order of the crystal, significantly affecting the dielectric properties.

This work provides a new way to develop high-performance dielectric materials for the capacitors of the future. Capacitors are the fundamental building blocks required for virtually all the electronic and electrical devices we currently rely on. In a very real sense, a new generation of capacitors using these new dielectric materials will affect all current 'high-tech' areas, including energy storage.

W. Hu et al, *Chem. Mater.* 27, 4934 (2015).

FINDING HIDDEN GOLD

Finding gold can be a tricky business so understanding the mineral fingerprints of gold-rich regions is a great help to exploration. Two minerals that often go hand-in-hand with gold are lead ores and sulfosalts of bismuth. These minerals can trap nanoscale gold and copper during the processes of their formation, resulting in nanoscale gold that can be economically viable, if it can be identified.



Scanning transmission electron micrograph showing the atomic arrangement in the new mineral. Heavier elements show up as darker dots.

During their many years of research Dr Cristi Ciobanu and her colleagues at the University of Adelaide (UoA) have been using AMMRF's advanced microscopy to gain in depth knowledge about the structure of these minerals. Previous discoveries by this group found that micro to nanoscale processes are responsible for gold-enrichment in common sulfide ores. From these findings they concluded that fine gold inclusions must be linked to gradual changes in copper concentration within the bismuth minerals, but only now can these conclusions be directly verified.

The new aberration-corrected transmission electron microscope in the AMMRF at UoA takes Dr Ciobanu's investigations to the atomic level. By directly visualising the structural arrangement of atoms in the complex crystal lattice of the sulfosalts, they have identified a new mineral similar to neyite and cuproneyite. The analytical capability of the new instrument has enabled the researchers to directly identify the arrangement of different elements within this new mineral's crystal lattice. The discovery of this new sulfosalt has important implications for elemental distribution both within sulfosalts, and at the larger mineral and deposit scale, opening up new possibilities for economically viable ore deposits.

essential: equine industry

CHALLENGE

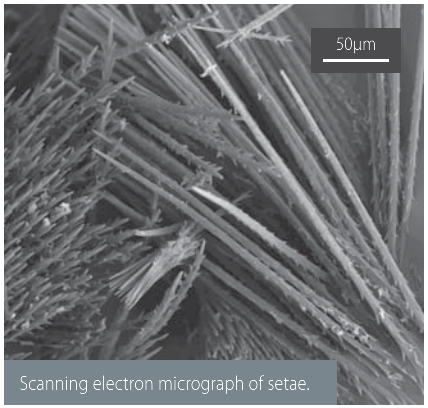
Australian horse racing is a multi-billion dollar a year industry and every thoroughbred foal is a potential million-dollar race winner. Many are conceived as the result of stud services valued at hundreds of thousands of dollars. The loss of a foal is an enormous real and potential economic loss for breeders.

In Australia's eastern states the processionary caterpillar (*Ochrogaster lunifer*) threatens this industry. It has been linked to equine amnionitis and foetal loss. This causes about one third of horse abortions in affected areas – the single biggest known cause of abortions in the thoroughbred breeding industry.

At night in late autumn the caterpillars cluster together in nests, in or around the trees on which they feed. Ingestion of larvae or cast skins by pregnant mares, results in the harpoon-like hairs (setae) penetrating the gut, migrating through to the uterus and causing the mares to abort their foetuses. We need to understand the environmental distribution of shed setae, and how they break down over time.

SOLUTION

An ARC Linkage Project brings together the University of Queensland (UQ) and industry partners AusVet Animal Health Services, Hunter Valley Equine Research Centre and members of the thoroughbred industry to research the risk presented by the setae, and to determine how best to manage it. Dr Bronwen Cribb used scanning electron microscopy in the AMMRF at UQ and discovered that each caterpillar sheds 2–2.5 million setae over its lifetime. Also, the dangerous forms of setae occur only on late stage caterpillars and in the chambers where they pupate. Research into how setae disperse and degrade in the environment is continuing.



Scanning electron micrograph of setae.

IMPACT

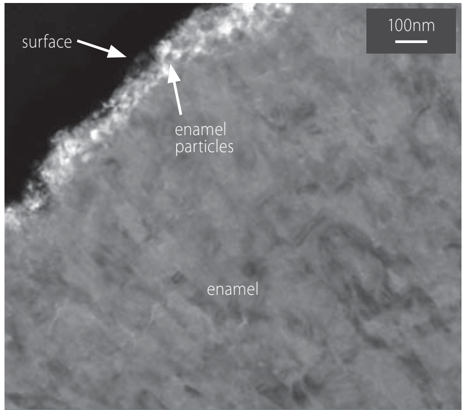
Development of improved strategies to protect pregnant mares will provide:

- greater economic security for thoroughbred horse breeders
- annual savings to the thoroughbred industry of at least $6 million
- significant financial benefit to the agricultural and recreational equine sectors
- improved equine health.

HOW TOUGH ARE YOUR TEETH?

Excessive tooth wear can adversely affect human oral functions such as chewing, which in turn affects the quality of a person's life. With increasing longevity and the expectation of keeping your own teeth, tooth wear is an important issue.

Tooth enamel consists of calcium phosphate crystals in the form of hydroxyapatite bound together by a protein matrix. This protein matrix makes enamel tougher than current artificial crown ceramics and the current dental composites used for fillings. Dr Joseph Arsecularatne and Prof. Mark Hoffman at the University of NSW (UNSW) are uncovering the microscopic wear processes in both human enamel and artificial materials. They use focussed ion beam milling, scanning and transmission electron microscopy and energy dispersive spectroscopy in the AMMRF at UNSW together with nanoindentation studies to visualise the microstructure of the materials before and after wear.



TEM image of human enamel after wear showing wear particles (white) adhering to the surface.

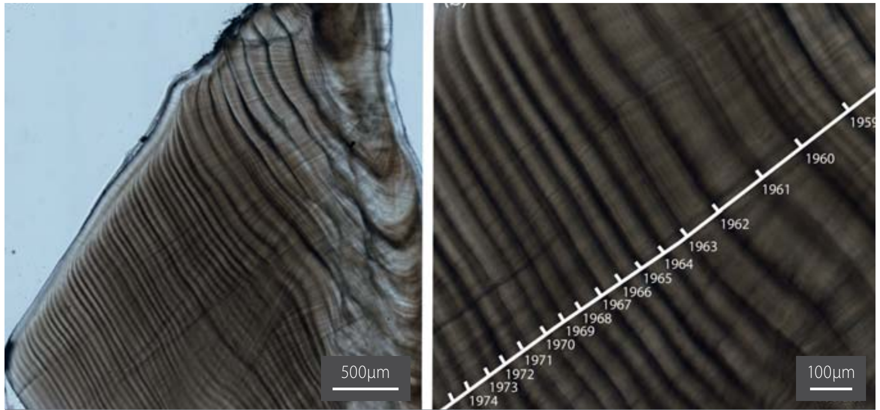
The researchers create different oral conditions with saliva and acids to mimic an acidic diet, and apply forces to replicate chewing or grinding of teeth. They show that many factors influence wear behaviour. For example, although saliva remineralises enamel after acid erosion, the repaired enamel is never as tough as undamaged enamel. Also, irregularities in the microstructure act as initiation sites for cracks, which, when increased force is applied, often led to severe subsurface cracking and greater damage to teeth or crowns.

Potentially more wear-resistant crown materials are currently being designed. High entropy alloys that contain combinations of multiple biocompatible metals are now receiving increasing attention for dental applications.

LISTENING TO PAST ENVIRONMENTS

Our climate is changing fast and water temperatures in the ocean have been rising over the past few decades. Being able to predict how such changes in climate and the ocean environment will affect the growth of marine species is crucial, but has not been fully explored due to the lack of long term growth datasets.

Ms Joyce Ong, a postgraduate student at the University of Western Australia (UWA), with local and international collaborators, has published a study in *Scientific Reports*, examining how historical climate changes over the past few decades have affected the growth of the mangrove jack snapper in tropical north-western Australia.



Light micrograph of a *Lutjanus argentimaculatus* (mangrove jack) otolith section with a close up image of the rings labelled with corresponding calendar years.

They focused on the tiny ear stones (otoliths) of this fish, which contain rings very similar to those seen in a tree trunk. These rings enable researchers to determine both the age and the growth rate of these fish. By using light microscopy in the AMMRF at UWA to image these tiny structures, the researchers found that over the past few decades these fish grew faster when the waters along the north-west coast were warmer and less salty.

By understanding how fish have responded in the past to climate changes and which environmental factors are crucial for their growth, researchers can now predict how fish might respond in the future. This knowledge will help us to better conserve the ocean ecosystem and the sustainability of our fisheries.

Ong, J. J. L. et al. *Sci. Rep.* 5, 10859; doi: 10.1038/srep10859, 2015.

essential: *fuel efficiency*

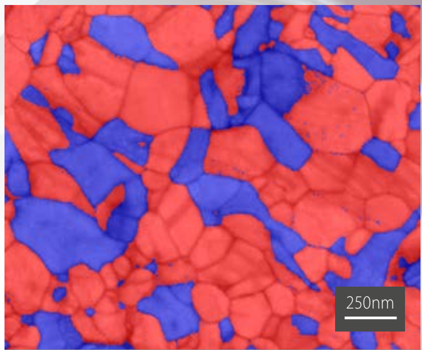
CHALLENGE

With a growing global population and the impact of carbon emissions on climate, demand continues to grow for more fuel-efficient cars with reduced emissions. Car manufacturers now use advanced high strength steels (AHSS) instead of conventional ones to make cars lighter. However, the current AHSSs are at their limit of strength, malleability and cost. For further weight savings a new approach is needed.

SOLUTION

AHSS are strengthened by controlling the types of crystal lattices present in the steel. Current AHSS for vehicles contain several different atomic arrangements, such as ferrite, bainite and martensite. PhD student Mehdi Eizadjou, working with Prof. Simon Ringer at the University of Sydney (UoS) has combined computational and experimental approaches to design a new AHSS that achieves twice the strength and retains similar malleability of many AHSSs in common use. The new steel has an ultrafine microstructure containing a hard phase (martensite or ultrafine ferrite) and a malleable phase (austenite) in an iron–manganese–aluminium–carbon alloy.

Through a research collaboration, China Steel produces the steels designed by the research team. By using the AMMRF at UoS for atom probe tomography, scanning electron microscopy with transmission Kikuchi diffraction, and transmission electron microscopy, Mr Eizadjou was able to assess the steel microstructures and evaluate the formation of the relatively unstable austenite. He found that by keeping the individual crystals of austenite smaller than 300 nanometres and controlling the chemical composition, austenite remained stable at room temperature.



TKD image showing crystals of austenite (red) and ferrite (blue) . Movie (via QR code): Atom probe dataset of an AHSS. Each red dot represents an atom of manganese; blue, aluminium; black, carbon.

Mr Eizadjou found that unlike most AHSSs his new steel only needed a few minutes heating time at 650°C to achieve the optimal properties.

H. Yen, et al., *Acta Materialia* 82, 100, 2015

IMPACT

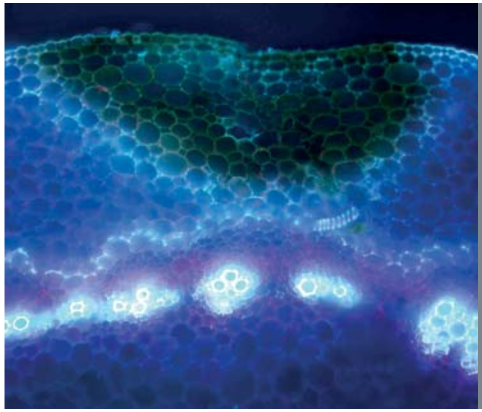
A greatly improved steel for automotive use has been created through alloy design at the nano-scale. It will:

- allow the fabrication of complex shapes
- absorb the energy of collisions
- enable lighter and more fuel-efficient vehicles
- be cost-effective for the car industry, due to its short heating time

STOPPING STEM ROT

The most cost-effective means to control plant pathogens in economically important crops is to develop resistance within the plants. An understanding of how crops become naturally resistant to Australia's important fungal and viral pathogens is fundamental to improving the management of crop diseases. However, little is actually known about the processes involved. The Plant Pathology Group at the University of Western Australia (UWA) has been working with the AMMRF at UWA to define key host resistances of Brassicas to important pathogens. Important Brassica crops include canola, mustard, cabbages, cauliflower and broccoli.

In a Linkage Project with the Department of Agriculture and Food Western Australia, A/Prof. Peta Clode used confocal microscopy in the AMMRF at UWA to show that the pathogen, *Sclerotinia sclerotiorum* invades the vascular system of highly susceptible types of Brassica causing rapid rotting of the stems. However, in contrast, resistant Brassicas restrict growth of the fungus by impeding its progress towards stem vascular tissues. They do this by producing more cell layers in the outer part of the stem and rapid lignification of the surrounding tissue. This initiates the rapid death of cells around the infected area.



Stem cross section of canola showing strong auto-flourescence surrounding a lesion and in the endodermis, demonstrating lignin barriers formed against the fungal pathogen Sclerotinia.

Lignin is the tough structural molecule of wood and lignification is a common part of the resistance puzzle in Brassicas, protecting vascular tissue from invasion. The resistance mechanisms identified in these studies will be highly valuable for targeted breeding programs to develop new disease-resistant cultivars. They will also enable new, more effective strategies to be developed for managing crop diseases in Australia.

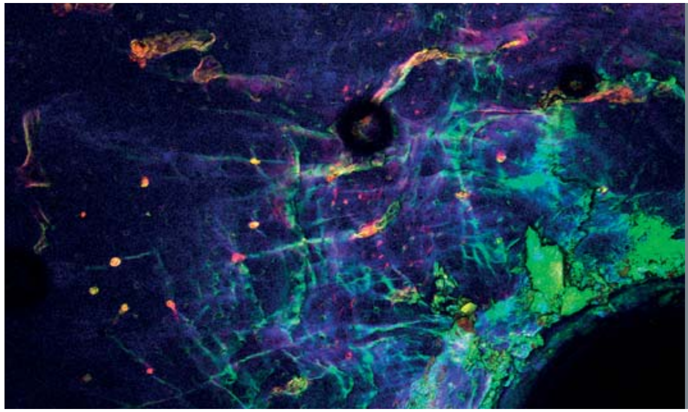
M. Uloth et al., *Annals of Botany*, doi:10.1093/aob/mcv1502015, 2015

STRAIGHTENING TEETH WITHOUT THE STRESS

Orthodontists often use miniscrews – temporary anchorage devices (TADs) as attachment points for the wires used to realign teeth. Miniscrews are inserted directly into a patient's bone and provide a secure anchor point from which pressure is exerted to encourage teeth to move to the desired position.

Miniscrews are popular because they are relatively cheap, surgically easy to insert, have multiple placement options, and most importantly, don't depend on patient compliance and unsightly headgear. However, the success rate of TADs is not particularly high with some screws moving or even pulling out altogether.

Clinical observations suggest a higher failure rate when the screws are put into areas where the compact bone is thicker. Dentist and postgraduate student Dr Melissa Nguyen at the University of Adelaide (UoA) is studying this at the tissue level by using confocal microscopy in the AMMRF at the UoA. Stresses caused by the insertion of screws cause microdamage to the bone in the form of microcracks. This causes the bone to remodel itself around the screws. First, specialised cells remove damaged areas before other cells move in to deposit new bone. The initial removal of the damaged bone is the cause of wobbly screws. Dr Nguyen has found a network of cracks emanating from the screw insertion points and her early results appear consistent with the clinical observations.



Confocal image showing cracks caused by a 1.5mm diameter TAD on 1mm thick compact bovine bone. Microcracks caused by screw insertion are shown in green and by removal, in blue.

By understanding how bone thickness and insertion torque lead to microcracks, orthodontists should be able to position screws more reliably and control the insertion forces, thereby reducing miniscrew failures.

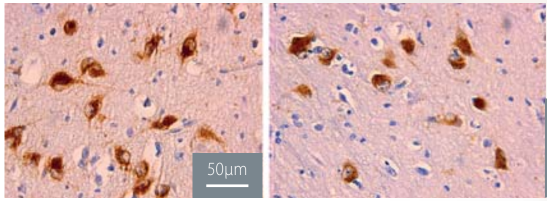
essential: healthy sleep

CHALLENGE

Sudden infant death syndrome or SIDS is the most common form of death for post neonatal infants in the developed world, with thousands of SIDS deaths every year worldwide. SIDS remains a non-definable diagnosis. Despite a thorough investigation by police and the coroner, there are no clear answers for parents who have lost a child.

Why do seemingly healthy infants stop breathing during sleep and fail to wake up? Failure of arousal and cessation of breathing are also common symptoms of other sleep-related disorders such as obstructive sleep apnoea, which affects 1 in 80 children and over a million adults in Australia.

SOLUTION



Light micrograph showing orexin-stained neurons in brown. Normal infant brain, left, and a SIDS infant brain, right.

Mr Nicholas Hunt, Dr Rita Machaalani and Prof. Karen Waters at the University of Sydney (UoS) are examining the neurological connections that induce arousal. These are complex with several neuropeptides critical to the arousal function. Using the AMMRF at the UoS this group has shown that one of these neuropeptides, orexin, is reduced by 20% in SIDS babies. This loss of orexin also occurs in infant animal models of SIDS. These animals also demonstrated impaired arousal following cessation of breathing or exposure to elevated carbon dioxide and reduced oxygen (hypercapnic hypoxia), a prominent risk factor for SIDS generated by prone sleeping. In a previous study they also showed that exposure to hypoxia reduced the production of orexin in baby animals. The team's current studies are examining the mechanism by which this occurs. Initial data suggests it is mediated by the modification of a protein called PERK, which reduces the production of a whole suite of proteins.

These studies establish a direct pathway between risk factors for SIDS and the regulation of sleep and arousal so vital to an infant's survival. The pathway for reduced production of orexin in SIDS has broader implications for childhood and adult sleep-related disorders such as obstructive sleep apnoea, where reduced orexin levels have also been seen, and where hypercapnic hypoxia is also an issue. Orexin may also play a role in neurological disorders like Alzheimer's and Parkinson's that have secondary sleep dysfunction as the diseases progress.

Ref. N. Hunt et al., *Acta Neuropathol.*, 130(2), 185, 2015
Ref. N. Hunt et al., *Neuropathology of Aging*, 36(2), 292, 2015

IMPACT

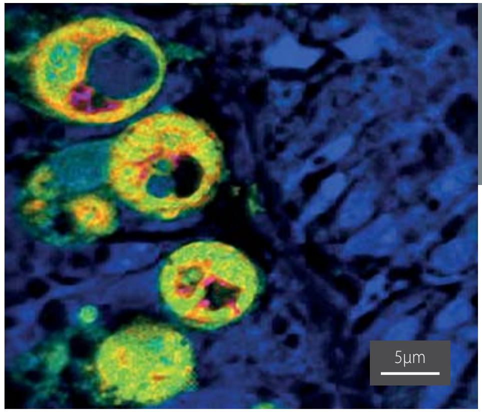
Having identified the pathway connecting hypercapnic hypoxia to reduced numbers of orexin neurons and reduced arousal, it may soon be possible to save lives and improve the quality of sleep for millions of people by:

- developing methods that identify infants at risk of SIDS
- targeting the orexin system for sleep therapy in infants at risk of SIDS
- potentially targeting the orexin pathway for drug therapies for sleep apnoea without the need for intrusive devices.

LOOKING DEEP INTO CORALS

Reef-building corals are among the most productive tropical marine ecosystems on Earth. At their heart are microalgae called Symbiodinium that live inside coral cells and convert enormous amounts of sunlight into sugars available to the coral host. Sunlight therefore, is key for corals. Previous studies suggested that the amount of light and oxygen reaching individual microalgae is highly variable, even within a single coral polyp. However, until now it was unknown whether these differences affected the function of microalgae within coral tissues.

PhD student Daniel Wangpraseurt and Dr Mathieu Pernice from the University of Technology Sydney (UTS), together with local and international collaborators, used the flagship NanoSIMS in the AMMRF at the University of Western Australia (UWA) to study the metabolic activity of individual Symbiodinium cells along microscale gradients of light and oxygen within coral tissue. This is the first experimental demonstration of functional diversity of Symbiodinium along these microgradients. Within the same single coral polyp, the amount of sugar produced via photosynthesis in individual symbiodinium cells varied by about six fold depending on the local light and oxygen levels. Interestingly, as a 15-fold reduction in light led to only a 6.5-fold reduction in sugar production, light-harvesting efficiency may have adapted to the lower light levels in the microalgae found deeper within the coral tissue. These results could have important consequences for coral responses to environmental stress such as bleaching, as they suggest the presence of distinct populations of Symbiodinium that could act as a reservoir of variation, providing selective advantage to corals.



NanoSIMS image showing photosynthetic assimilation of carbon in the Symbiodinium cells within coral tissue. The colour scale ranges from blue, which corresponds to natural abundance of $^{13}C/^{12}C$) to red indicating a 10-fold enrichment of experimental ^{13}C.

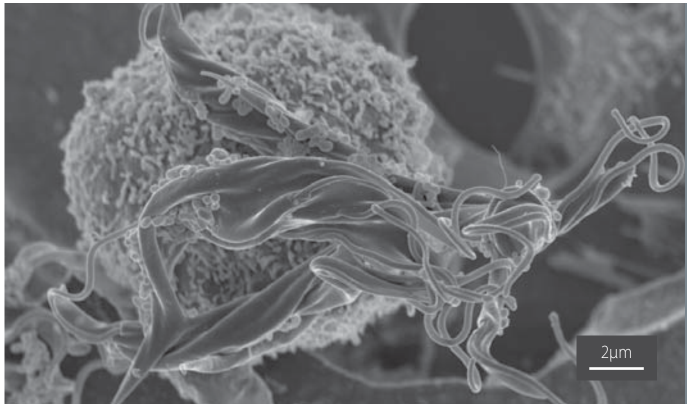
TRACKING PARASITES OF MAN AND BEAST

The woylie *(Bettongia penicillata)* is a critically endangered marsupial whose population has declined by more than 90% in the last 10 years. The trypanosome parasite *Trypanosoma copemani* has been implicated in this decline.

Trypanosomes are vector-borne protozoa that infect vertebrates. They are broadly distributed, infecting a wide range of hosts including both humans and domestic animals. Most of our knowledge about trypanosomes comes from studying *T. brucei* and *T. cruzi*, which infect humans. These cause sleeping sickness and Chagas disease respectively. In Australia, trypanosomes naturally infect wildlife, however, we don't know much about their potential to cause disease or how they are transmitted.

Prof. Andrew Thompson's group at Murdoch University has joined forces with the AMMRF at UWA through A/Prof. Peta Clode to characterise trypanosomes isolated from Australian wildlife, particularly *T. copemani*. The researchers are deciphering the interactions that take place as the parasites invade the host cells by combining genetic and molecular analyses with correlative light, scanning and transmission electron microscopy for structural and functional imaging. They found remarkable similarities between trypanosomes from woylies and the human pathogen *T. cruzi*. This raises questions of biosecurity concerning the potential transmission of *T. cruzi* to humans by Australian wildlife if *T. cruzi* are able to enter this wildlife reservoir.

Together, data from this program are informing decision making on animal conservation and relocation programs, especially in regard to the spread of disease in endangered wildlife. Potential biosecurity issues relating to transmission of exotic, pathogenic human trypanosomes by Australian marsupials are also being identified.



Scanning electron micrograph of *T. copemani* attached to a marsupial cell.

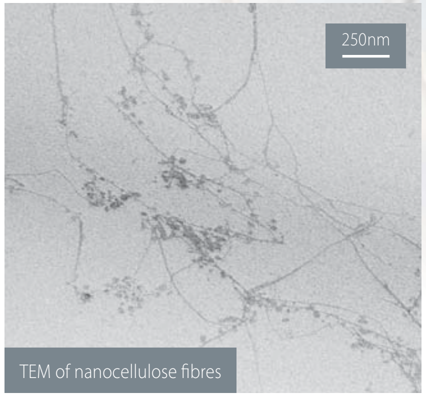
essential: outback enterprise

CHALLENGE

Carbon fibres are a powerful way to strengthen many materials but they are expensive to produce and are derived from non-renewable petrochemical sources. To make carbon fibre more cost-effective and sustainable, a low-energy process must be developed based on a renewable resource with simple chemistry.

SOLUTION

Prof. Darren Martin and his team at the University of Queensland (UQ) have patented a low-cost process for extracting very long and very thin (3-4 nm) nanocellulose fibrils from spinifex grass. Spinifex grasses are the dominant plants in the driest regions of Australia covering around 30% of the continent. The UQ team is partnering with the Camooweal-based Dugalunji Aboriginal Corporation to share traditional knowledge of the spinifex and intellectual property of the process and final product.



TEM of nanocellulose fibres

The fibres that the team produces from spinifex are the longest, thinnest and toughest nanocellulose materials reported to date. The unique chemical composition that has adapted spinifex to the harsh desert conditions also makes the nanofibres easy to isolate and unusually flexible and tough. Once isolated, the nanocellulose fibrils are heated up to high temperatures to form pure carbon fibres, the commercially relevant end product. The research team relies on electron and atomic force microscopy in the AMMRF at UQ for characterising the structure and mechanical properties of these renewable nanomaterials.

Prof. Martin's team is now working to validate several commercial applications.

Nasim Amiralian et al., *RSC Adv.*, 5, 32124, 2015

IMPACT

A uniquely Australian resource to produce high-quality, low-cost carbon fibres has a potentially huge range of industrial applications. Once commercialised, this will contribute to:

- capturing a share of the $14 billion carbon-fibre-composite market
- building new industries on sustainable resources
- new, valuable enterprises for remote Aboriginal communities vulnerable to economic hardship
- regional regeneration
- improved materials for packaging, tyres, planes and super-light electric cars

PROTECTING PROTEIN DRUGS

Protein therapeutics are becoming more prevalent in the treatment of disease. However, as proteins are relatively unstable and readily degraded, there is a need to develop effective delivery systems.

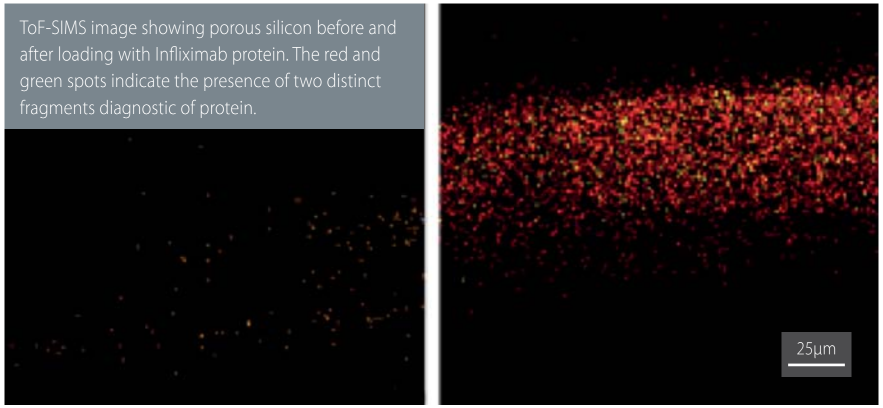
Non-healing chronic wounds are a significant problem, particularly in aged care. A protein called TNF-α, was found to be elevated in these wounds. An antibody specific to TNF-α , is available (Infliximab) and is effective in reducing TNF-α and promoting wound healing. However, ingesting high-doses of Infliximab, can produce dangerous side effects that require treatment to be discontinued. An effective system for delivering Infliximab directly to wounds should overcome this problem.

Dr Steven McInnes, Prof. Nicolas Voelcker and colleagues at the University of South Australia (UniSA) have developed porous silicon (pSi) that can be easily engineered with various structures and pore sizes. They used the ToF-SIMS in the AMMRF at UniSA to evaluate and optimise the structures for their ability to carry large quantities of therapeutic molecules, including Infliximab. They can also control the charge on the particles, which helps regulate the rate of protein release.

When they tested their engineered particles for the controlled release of Infliximab in simulated chronic wound environments they found a steady release from the pSi microparticles over at least 8 days. The released antibody remained able to neutralize TNF-α.

These results suggest that the pSi delivery vehicle is suitable for clinical applications in chronic wound therapy. Future work will focus on the development of pSi nanoparticle delivery systems for incorporation into topical creams and bandages.

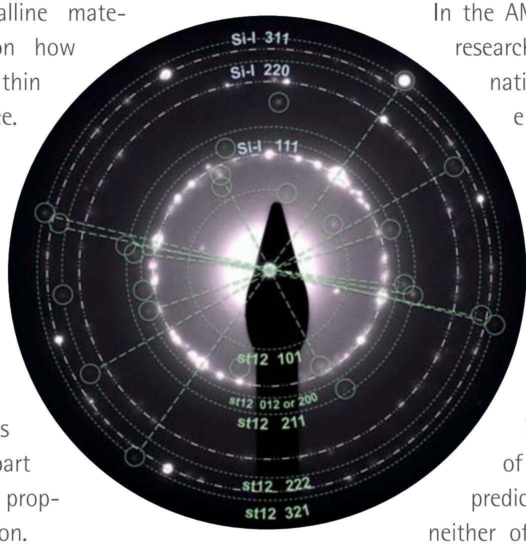
Steven McInnes et al., *J. Mater. Chem. B*, 3, 4123, 2015



ToF-SIMS image showing porous silicon before and after loading with Infliximab protein. The red and green spots indicate the presence of two distinct fragments diagnostic of protein.

MICROEXPLOSIONS SHAPE NEW SILICON

Silicon is an extremely important material of the modern age, with applications forming the basis of the electronics industry and solar technology. Its properties, like those of other crystalline materials, depend on how its atoms sit within the crystal lattice. Normally, silicon atoms form a diamond cubic crystal structure. However, if they can be forced to take up different arrangements they may impart new, and useful properties to the silicon.



Prof. Andrei Rode, Prof. Jim Williams, A/Prof. Jodie Bradby, and colleagues at the Australian National University (ANU) and University College London have used electron microscopy and computer modeling to predict potential alternative structures for silicon. They already knew that ordinary materials can adopt new and unusual crystal structures when exposed to extraordinarily high pressure and temperature. By using ultrashort (100 quadrillionths of a second) laser pulses they induced microexplosions inside the silicon to create these extremely high pressures and temperatures. This process effectively creates a contained plasma that then cools incredibly quickly, so new atomic arrangements form energetically stable structures.

In the AMMRF at ANU the researchers used a combination of advanced electron microscopy techniques to visualise and measure the new crystalline structures with electron diffraction (see image). They identified two of the computer-predicted structures, neither of which had been previously experimentally reported. Several additional structures were also observed that are now being studied in more detail. The computer predictions suggest that the new structures could have semiconducting to semi-metallic and possibly superconducting properties.

These findings and methods are helping pave the way for exciting new materials to be developed.

Rapp et al. *Nat. Commun.*, 6, Article number: 7555, 2015

Image from the article above, courtesy of *Nature Communications*, MacMillan Publishers Ltd.

essential: manufacturing

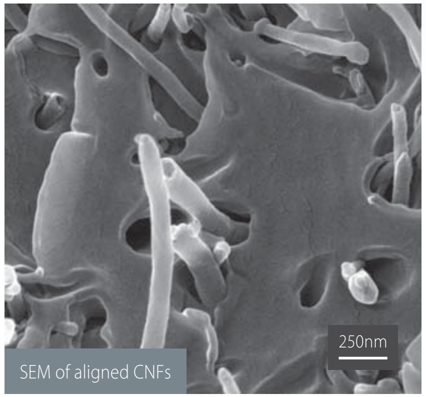
CHALLENGE

Aircraft such as the Airbus A380, A350 and Boeing 787 are using increasing amounts of sophisticated composites in their construction. In such aviation applications, good electrical conductivity helps to protect against lightning strikes and electromagnetic interference. It also makes damage within composite aircraft structures easier to detect. For mining equipment and the transport and storage of oil and gas, good electrical conductivity is also needed to meet fire-retardant antistatic regulations.

Thermosetting epoxy polymers reinforced with fibres are widely used for structural parts and as adhesives. However, they are not good conductors of electricity and they can fracture relatively easily. Using current manufacturing techniques, carbon nanofibres (CNFs) impart moderate improvements to both strength and electrical conductivity to such polymers, plastics and rubber. There is great demand for further enhancement of these composites for aviation and mining applications.

SOLUTION

PhD student Mr Raj Ladani at RMIT has looked at ways to improve carbon-fibre-reinforced epoxy-resin materials. He found that applying an electric current after the carbon fibres were mixed into the liquid plastic causes them to align in the direction of the current. This alignment is locked in when the mixture sets. Mr Ladani has used electron microscopy in the AMMRF Linked Lab at RMIT to visualise the aligned carbon fibres. He found that by adding just 1% by weight of CNFs and aligning them in the composite, toughness is increased by 27% and electrical conductivity five-fold over unaligned composite. This is 11 times tougher and ten million times more conductive than unreinforced epoxy. The aligned network of CNFs can strengthen and impart electrical conductivity to epoxy used as an adhesive and as a structural component. Furthermore it can be used as an integral sensor to detect any damage within the composites as damage changes the electrical conductivity.



SEM of aligned CNFs

IMPACT

Aligned CNF composites will increase the range of applications for composites in the aerospace, and oil and gas industries where electrical conductivity is essential. Demand for composites grew in these industries by 10.7% and 5.2% respectively in 2014. This advance will contribute to:

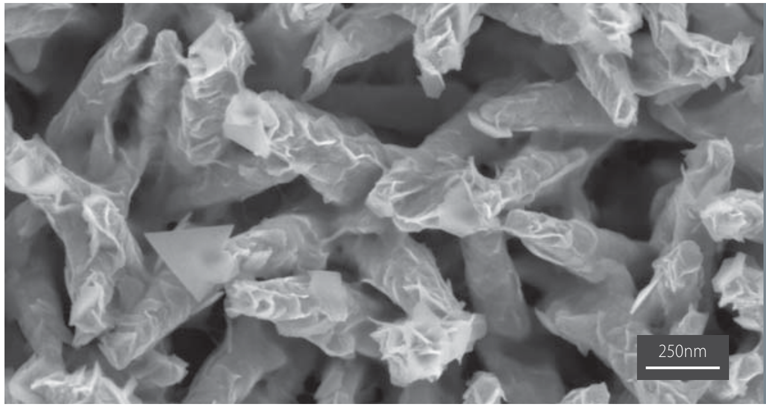
- a bigger share for Australia in the $5–8bn composites market
- more fuel-efficient, lower emission planes
- more cost-effective transport and storage in oil and gas tanks and pipes.

GOLDEN GLUCOSE SENSOR

As diabetes becomes more prevalent in our society there is an increasing demand for more sensitive and accurate glucose detection. Current enzyme-based glucose sensors are limited to restricted operating temperatures and pH. They are also expensive to produce and can be chemically unstable. A non-enzymatic sensor would overcome these problems.

PhD student Victoria Coyle and her supervisors at RMIT are developing a nanostructured electrochemical glucose sensor covered with gold nanospikes, each approximately 750nm long. The large surface area of the nanospikes is covered with hydroxyl groups that oxidise the glucose during sensing. The oxidation process reduces the electrical potential of the sensor. This change occurs at a very specific voltage, which is different to that for other molecules in the sample being tested. The angular, arrow-like shape of the nanospikes was shown to be the most efficient structure so far for distinguishing glucose's unique voltage signature. Because the structures are so important for selectivity, optimisation is critical for maximum efficiency. Ms Coyle uses scanning and transmission electron microscopy and elemental analysis in the AMMRF Linked Lab at RMIT to confirm the shape, size, composition and distribution of the nanospikes over the surface. Generally speaking, the nanostructured surface is 400% more sensitive to glucose than a flat gold surface.

Ms Coyle also found that adding cobalt oxide to the nanospikes enhanced glucose sensing even further. She has determined the most synergistic combination and is well on her way to making a viable non-enzymatic glucose sensor for real world applications.

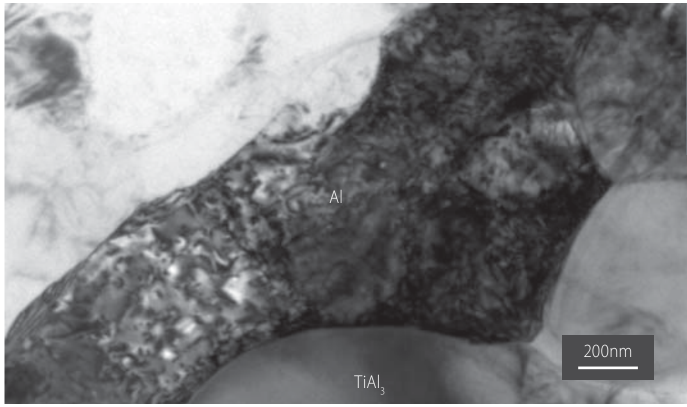


Scanning electron micrograph of gold nanospikes coated with cobalt oxide flakes.

METAL SANDWICH IS BEST ROLLED AND BAKED

Dislocations are imperfections in crystal lattices. These are important in metallurgy because they can affect the strength and ductility of a metal. The density of these dislocations has a critical impact on these properties. Mechanical deformation, such as the process of rolling a thin sheet of metal from a thick block, causes an increase in the number of dislocations with the increase in strain. This tends to make the metal harder but more brittle. Baking the rolled metal rebuilds its crystal structure with far fewer dislocations, improving its strength and maintaining its ductility.

Dr H. Yu, a research fellow at the University of Wollongong, and his colleagues, are interested in a laminate that sandwiches a layer of titanium between two layers of aluminum (Al/Ti/Al). This multilayer sheet material bonds together through rolling. Following heat treatment, the laminate is transformed into a high-performance, three-layered laminate containing nanograined Ti, coarse-grained Al and particles of $TiAl_3$. This is a new type of strong multilayer material for potential use in aerospace applications. The research team used the flagship focused ion beam in the AMMRF at the University of NSW to prepare site-specific specimens to study the development of microstructure in the baked laminate. They found a surprisingly high number of dislocations in the pure aluminium zone at the interface with the $TiAl_3$ particles. This was associated with a relatively stable interlocking microstructure. Dr Yu suggests this is responsible for the enhanced strength and ductility.



Abnormally high dislocation density (black wiggly lines) in Al of Al/Ti/Al laminate.

H. Yu et al. Philosophical Magazine Letters, 94 (11), pp732, 2014

This article was selected by Taylor & Francis as 'Physics Best 2014'.

SLEEK MOTTLED MAMMOTH UNDER THE MICROSCOPE

Woolly mammoths were frequently preserved in the Arctic ice leaving abundant material for researchers to study. The first complete baby woolly mammoth (7-8 months old) is around 46,000 years old and was found in north-eastern Siberia. PhD student Silvana Tridico from Murdoch University has worked with international colleagues and A/Prof. Paul Rigby in the AMMRF at UWA to investigate the structure of woolly mammoth hair to understand how its structure could relate to its function in the living animal. The underhairs are very springy and coiled but smooth, which would have encouraged loose intertwining to give a puffy arrangement but prevented matting. This smoothness extended to the overlying hairs, also keeping them separate. Microscopy revealed that the hairs were unusual in having multiple cores, called medullae. This is thought to contribute to the stiffness of the hairs.

Multiphoton microscopy was particularly useful in analysing the multiple medullae as it makes it possible to look deep inside the hair without having to destroy it, keeping the sample intact for further analysis. It showed that structures previously seen in cross section are continuous in the longitudinal direction (see movie).

Ms Tridico also studied the preservation and colouration of the hairs. There was some insect and fungal damage but she could clearly see a variety of colouration patterns. These were compared to modern animal hairs, which suggested that mammoths probably appeared mottled or speckled rather than the rusty orange colour of common illustrations. This orange colour is probably due to breakdown products of the hair itself.

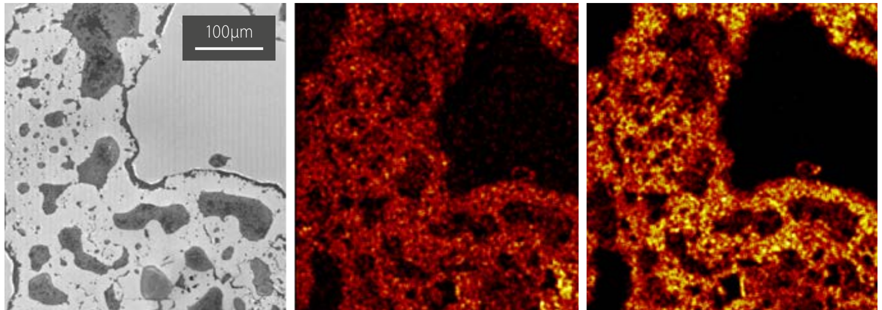
Silvana Tridico et al. *Quaternary Science Reviews*, 83, 68, 2014

Light micrograph of a woolly mammoth hair showing the long central medulla and some fungal damage showing up as projections out from the central medulla. Movie (via QR code): 3D reconstruction of multiphoton images of autofluorescent linear structures within a mammoth hair.

FINGERPRINTS GO MICRO

Fingermarks are produced by contact transfer of sweat, other skin secretions, and compounds picked up from the environment onto surfaces touched by a person's fingers. Each person's fingermarks have unique patterns that have been used for identification since the nineteenth century. By using modern technologies additional information can be collected about the molecular composition of fingermarks, allowing a detailed understanding of the impact that ageing has on fingermark viability for biometrics.

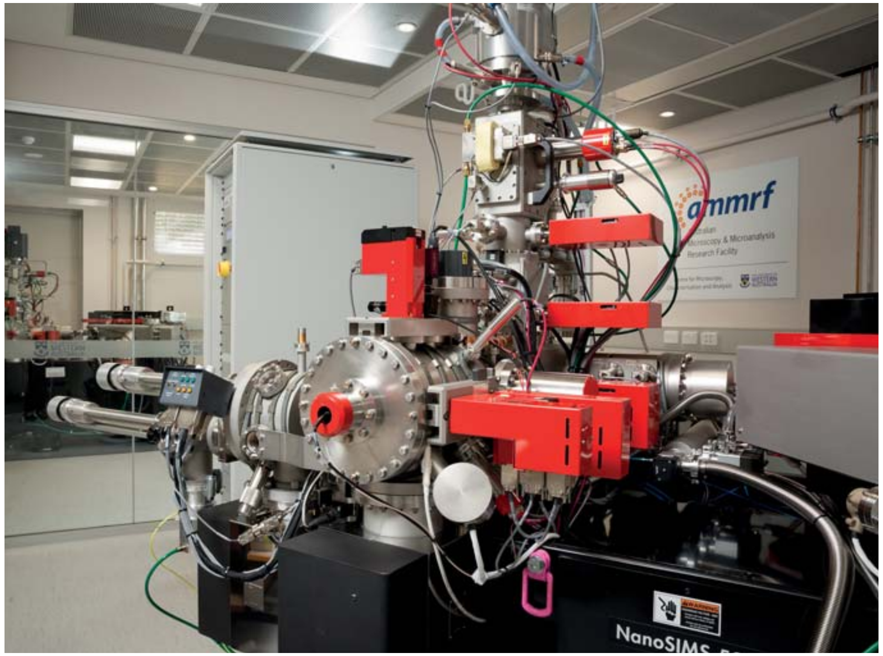
Dr Johan Gustafsson, Dr Taryn Guinan and Prof. Nico Voelcker at the University of South Australia (UniSA), as part of the ARC's Centre of Excellence in Convergent Bio-Nano Science and Technology, are identifying the distributions of molecular fingermark constituents using imaging mass spectrometry (IMS). Here, the aim is to catalogue forensically relevant compounds, such as illicit drugs. Fortuitously, by combining IMS with scanning electron microscopy (SEM), it is possible to assess the impact of environmental conditions such as temperature on molecular and morphological changes during fingermark ageing. The researchers are now combining their existing IMS analyses with time-of-flight secondary ion mass spectrometry (ToF-SIMS) in the AMMRF at UniSA. This is allowing comprehensive mapping of small molecules across entire fingermarks and sub-micrometre mapping of defined regions. SEM and combinatorial IMS will drive in-depth understanding of key changes in fingermark structure during ageing, and how these are mirrored by changes in small-molecule abundance and distribution. Preliminary work has confirmed that significant changes can occur, in structure and electrolyte distribution, across ageing fingermarks.



Scanning electron micrograph of a fingermark ridge (left) and two TOF-SIMS ion maps showing the distribution of sodium (centre) and potassium (right) across the ridge.

future focused

Our new capability positions us to continue supporting cutting-edge Australian research into the future.



THE UNIVERSITY OF WESTERN AUSTRALIA

NANOSIMS

A new NanoSIMS has been acquired by the University of Western Australia (UWA) as one of the partners of the Advanced Resource Characterisation Facility along with CSIRO and Curtin University. It will be run by the AMMRF at UWA and together with the existing NanoSIMS will provide significantly greater capacity for combined high-resolution imaging and mass spectrometry to determine the isotopic composition of minerals at the micro scale.

THE UNIVERSITY OF SYDNEY

SUPER-RESOLUTION MICROSCOPY

The new super-resolution instruments at the University of Sydney take optical microscopy beyond the previous limits of resolution by combining laser optics and clever computing. They allow researchers to visualise the activity of individual molecules inside cells with an unprecedented level of detail that will be increasingly important for the future of biomedical research.

THE UNIVERSITY OF WESTERN AUSTRALIA

THE UNIVERSITY of ADELAIDE

ATOMIC RESOLUTION TEM

Two FEI Titan transmission electron microscopes are now accessible through the AMMRF. Both are optimised for high performance imaging and microanalysis at atomic resolution. This high-resolution microscopy has broad applications in nanotechnology, the physical and geological sciences and potentially in some areas of biological element analysis. The Titans are also critical in mining and energy research and are already generating exciting new results in these areas (see p 22).

THE UNIVERSITY OF QUEENSLAND

X-RAY DIFFRACTION

Australia's highest-powered X-ray diffractometer has recently arrived in the AMMRF at the University of Queensland. It has a queue of users waiting to get the benefits of its highly sensitive measurements as they investigate solar cells, electronic devices membranes, fuel cells semiconductors and biomaterials.

Australian National University

X-RAY MICRO-TOMOGRAPHY (MICRO-CT)

CTLab, part of the AMMRF at the Australian National University (ANU), is capitalising on the outcomes of its longterm redevelopment of X-ray microtomography (micro-CT) technology and associated analytical tools. As a consequence of industry partnerships and the successful sale of their spin-off company, Lithicon, to FEI Company, CTLab will now provide access to the full range of CT scanners, designed and built at ANU. Sophisticated physical property mapping techniques complement the CT-based materials simulation tools for academic and industry clients, particularly those interested in composite materials, and 3D metrology of injection-moulded parts. CTLab now also provides a colour 3D print service.

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FEATURED IMAGE CREDITS

Cover: (Left) Atom Probe user photograph by Paul Blackmore. (Right) Specimen Preparation and (Centre) Light Microscopy photographs by Deirdre Molloy.

Back cover (Centre) and Inside Back Cover
Transmission electron micrograph of a cross section through an insect flight muscle showing the regular arrangement of actin and myosin proteins in the myofibril. The image is from a region where the actin and myosin filaments overlap. The larger circles are the myosin proteins and the smaller spots are the actin proteins. These proteins pull along each other to cause the muscle to contract.

Scale: the myosin molecules are approximately 46.6nm apart. © University of Sydney

Back cover: (Left) Micrograph by Neftali Flores-Rodriguez: ground state depletion (GSD) 2D reconstruction of microtubules in a HeLa cell stained with anti-alpha-tubulin antibody tagged with Alexa 647. This section of the cell shows the microtubule organisation centre.

(Right) Micrograph by Jenny Norman: scales from a granny moth showing their nanoscale structures.

Section Opener Images
Pages 4-5: Micrograph by Dr Melissa Nguyen – see story on p26.

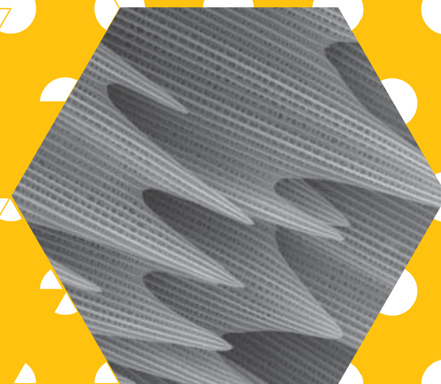
Pages 10-11: Diffraction pattern by Dr Hongwei Liu: colour enhanced selected area electron diffraction pattern of molybdenum trioxide collected in a transmission electron microscope. The most intense signal shows as yellow and the weakest as blue. MoO_3 is a source of molybdenum metal and it is also important as an oxidation catalyst. It has an orthorhombic crystal structure and may have application in electrochemical devices.

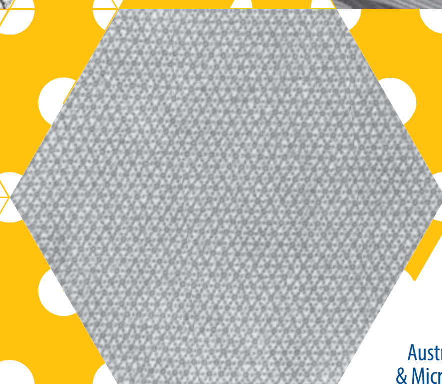
Pages 16-17: Micrograph by Dr Pat Trimby: electron backscatter diffraction image showing crystals of the mineral plagioclase (coloured) in amongst other minerals (grey) and glass (black) in one of the ancient Zagora slags. See p.20.

VIEWING VIDEO VIA QR CODES

To use the QR codes in this book you will need a smart device equipped with a camera and a QR code reader/ scanner application. Your can download a QR code reader from your phone's application store (e.g.: Android Market, Apple App Store, BlackBerry App World, etc.). Free apps usually work fine, for example, 'RL Classic' or 'QR reader'. Newer smartphones often have an app pre-installed on them.

Open the app and hold the phone steady with the QR code centred on the screen (as if to photograph it). When the scan is done you may get a prompt showing you the information in the QR code. In this case it's a web link that plays a video. Just respond to the prompt to visit the URL and enjoy the video. You may find the URL is stored in your browser history.
QR codes: pages 25 and 33.





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