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INQUIRY INTO NANOTECHNOLOGY IN NEW SOUTH WALES

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Inquiry into Nanotechnology in New South Wales

Submission to the Standing Committee on State Development by the Australian Microscopy and Microanalysis Research Facility

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Executive Summary

The opportunities offered by nanotechnology to impact on society are well documented. Enabling technologies will provide solutions to old problems, benefit the health of the global population, create employment and associated economic development. NSW has a real strength in nanomaterials science that, if given sufficient support, will eventually form the basis of whole new high-technology industries in this state.

Supporting the vast portfolio of nanotechnology research and development in NSW, the Australian Microscopy and Microanalysis Research Facility (AMMRF) provides advanced tools that enable scientists and engineers to observe and analyse nanoscale structure and processes. The ability for characterisation at this scale is a key to the successful development, commercialisation and application of nanotechnology.

Through a network of advanced microscopy and microanalysis platforms, the AMMRF enables ARC Centres of Excellence, CRCs, medical research institutes and other research organisations to achieve world class outcomes in NSW. The nanotechnology research programs supported include smart polymers, nanoporous materials, photonics, quantum technologies, light alloys, new generation steels, nanobiomedical and nanobiotechnology.

Analysis of nanomaterials undertaken by the AMMRF is safe and pose no health threat to the operators of instruments or the researchers. Typically the quantities of the materials handled during nanostructural analysis are very small. Many of the materials studied form an integral part of the nanostructure of the bulk material and therefore there is no risk of direct exposure of humans to these nanoparticles.

The AMMRF make the following recommendations regarding nanotechnology in NSW:

1. Research and development of nanotechnology must continue to be funded by state and federal governments. We cannot delay too long in facilitating and accelerating nanomaterials R&D because of the difficulties in entering what will already be a highly competitive market by the end of this decade.
2. The NSW State Government develops and funds education activities that will assist greatly in public acceptance of nanotechnology and the development of sustainable nanotechnology industries in Australia.
3. Australia must continue to invest in advanced microscopy and microanalysis infrastructure because the current and future challenges for science and technology all exist at the limits of spatial resolution and chemical sensitivity of many characterisation techniques. Future investment in time-resolved aberration-corrected transmission electron microscopy (TEM) and focussed ion beam platforms would benefit nanotechnology R&D and fill a gap in capability in NSW.

Introduction to Nanotechnology

What is Nanotechnology?

A nanometre is the unit of measure for 1 billionth of 1 metre or 1 nanometre is equal to 10^{-9} m. When referring to the nanoscale, therefore, we are describing phenomena, materials or process that are taking place at that length scale. Moreover, nanoscience refers to the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.

Nanotechnology is the ability to engineer materials at the nanoscale and includes the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometre scale. Engineering in this manner may occur either in a "top down" manner or "bottom up".

Top-down describes techniques where large masses are crushed and milled or in some way reduced in size until the particles produced are nanoscale (typically less than 100 nm). The lithography process in the electronics industry is the archetypal example of top-down manufacturing. Nanopowders, such as zinc oxide and titanium oxides, for use in cosmetics, pigments and paints are sometimes produced by simply crushing larger scale powders down to even smaller sizes.

Bottom-up fabrication describes the assembly of smaller sub-units (atoms or molecules) to make a larger structure. Widely used examples of bottom-up approaches include chemical and molecular synthesis and the atom-by-atom crystal growth methods (MBE and MOCVD).

Nanomaterials have key structural features on the nanometre scale. At this level, molecular and atomic architecture is responsible for bulk material properties and, as a consequence, entirely new behaviour and functions can be exploited. Examples of nanomaterials include ultra-light, ultra-strong materials, molecular electronics, high-performance biocompatible nanofilms, carbon nanotubes and ultra-efficient drug-delivery platforms. The application of these and other nanomaterials will create major breakthroughs in such areas as [1,2]:

- manufacturing and transportation technologies;
- biotechnology, medicine and healthcare;
- environmental protection and regeneration;
- information technology, computing and electronics;
- sustainable and high-value-added agriculture; and energy generation technologies.

NSW has a real strength in nanomaterials science that, if given sufficient support, will eventually form the basis of whole new high-technology industries in this state. However, it is widely accepted that only governments are positioned to provide the necessary levels of support to "the long-term, high-risk, high-gain research needed to create these new industries" [1]. Furthermore, we cannot delay too long in facilitating and accelerating nanomaterials R&D because of the difficulties in entering what will already be a highly competitive market by the end of this decade. As noted by the NSF [1]: "Those who participate in the 'nano revolution' stand to become very wealthy. Those who do not may find it increasingly difficult to afford the technological wonders that it engenders."

Recommendation 1: Research and development of nanotechnology must continue to be funded by state and federal governments.

Need for Advanced Microscopy and Microanalysis Capability to Analyse Nanostructure

The ability to undertake nanotechnology research and development and ultimately apply the outcomes of nanoscience to the benefit of society is dependent on our ability to observe and measure at the nanoscale. Analysis and characterisation of material structure and molecular processes at the nanoscale (also known as nanostructural analysis) is achieved through the use of advanced microscopy and microanalysis instruments.

Comprehensive suites of these instruments form core-enabling infrastructure for Australia, because advanced characterisation is essential to all of the National Research Priorities. Nanostructural analysis provides the molecular and atomic scale insights into major environmental problems that allow the development of the novel solutions required for an Environmentally Sustainable Australia. For example, advanced microscopy and microanalysis allows: the molecular characterisation of flora and fauna in our rivers, lakes and oceans; the development of new catalytic and energy technologies to transforming existing industries; and advanced understanding of soils that underpin approaches to reduce and even reverse erosion and salinity.

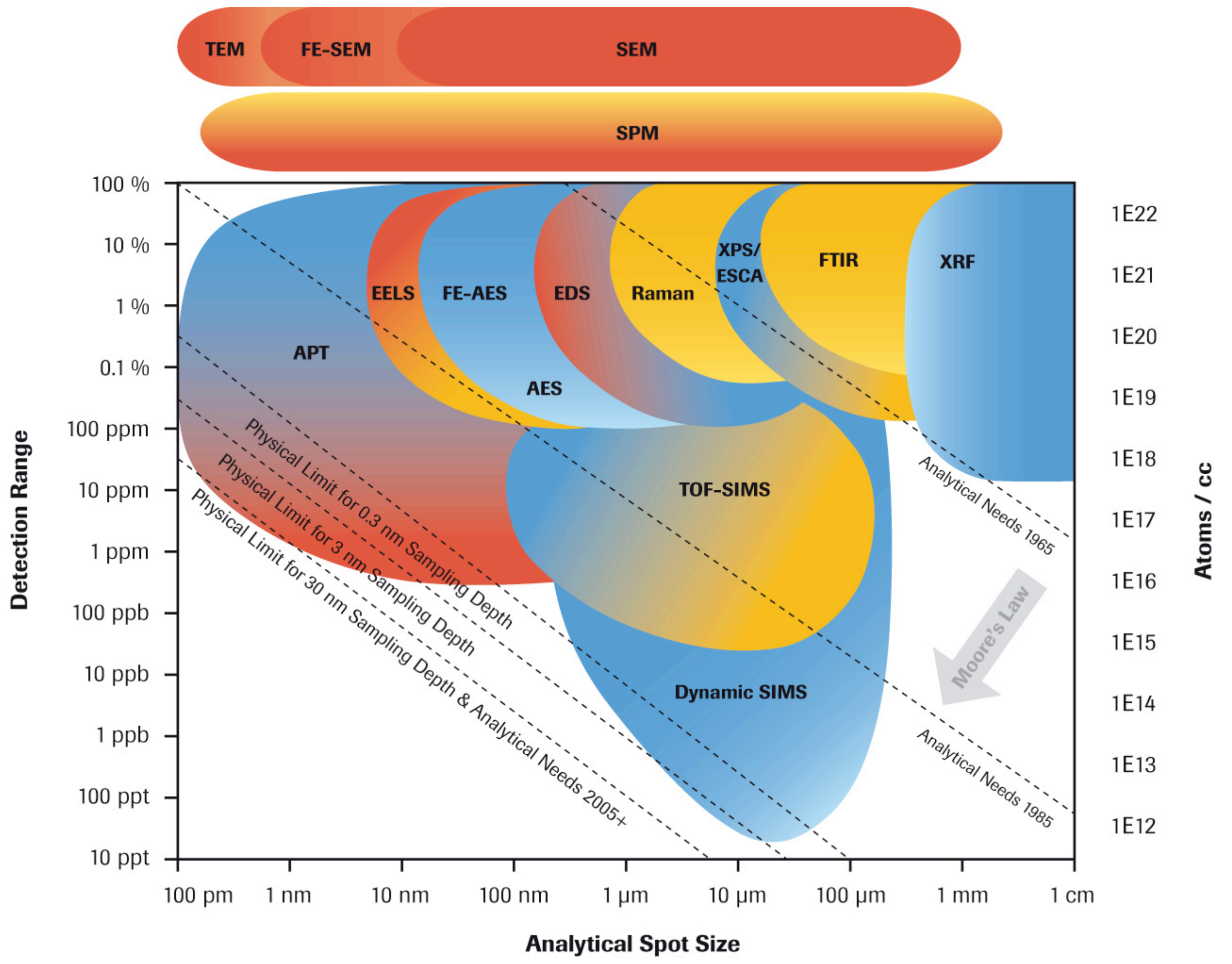
Though Promoting and Maintaining Good Health in the Australian population must be tackled from many angles, advanced microscopy and microanalysis is vital because it enables the cellular and molecular scale characterisation required to advance the science of biology, of disease, and of medicine. The range of imaging and analytical techniques afforded by advanced microscopy and microanalysis already is making inroads into our understanding, and therefore treatment, of key diseases that include diabetes, cancer and dementia.

Frontier Technologies for Building and Transforming Australian Industries are strongly dependent on the control, processing and characterisation of matter at the nanometre and atomic scales, making nanostructural analysis central to this priority. For example, scanned probe microscopies allow atomic resolution imaging and manipulation, thereby enabling the breakthrough sciences of nano-assembly and quantum computing; the nanoscale fabrication capabilities of focussed ion beam (FIB) systems and the atomic resolution imaging and spectroscopy of transmission electron microscopy (TEM) are fundamental to nanotechnology and nanophotonics; and advanced materials research is seeing the design of light alloys at the atomic scale and the creation of nanocomposites with unprecedented properties due to their nanoscale dispersed phases.

Finally, advanced microscopy and microanalysis contributes to Safeguarding Australia: it provides insights into the structural and molecular biology of invasive diseases and pests, and enables researchers to develop the advanced materials and nanotechnologies that underpin many transformational defence technologies.

Australia must continue to invest in nanostructural analysis infrastructure because the current and future challenges for our science and technology all exist at the limits of spatial resolution and chemical sensitivity of many characterisation techniques. For this reason, there is urgent need to not only maintain current capabilities but to push the boundaries and maintain leadership internationally by providing Australian researchers with the next generation of instruments that will enable tomorrow's science and technology.

Another key driver for maintaining expanding Australian microscopy and microanalysis capabilities is that, despite the value of and undisputed need for landmark facilities, the Australian synchrotron and the neutron scattering capabilities at the new reactor cannot access all—or even some of the most crucial—parameter space for modern science (Figure 1). Advanced microscopy and microanalysis instruments, and the much needed next generation instruments discussed below, access parameter space that is complementary to that covered by these landmark facilities and fundamental to Australia's research efforts.



Chemical bonding/ molecular information	
Elemental information	
Imaging and structural information	
TEM	Transmission Electron Microscopy
FE-SEM	Field Emission Scanning Electron Microscopy
SEM	Scanning Electron Microscopy
SPM	Scanning Probe Microscopy
XRF	X-ray Fluorescence
FTIR	Fourier Transform Infrared Spectroscopy
XPS/ESCA	X-ray Photoelectron Spectroscopy/Electron Spectroscopy for Chemical Analysis
TOF-SIMS	Time of Flight-Secondary Ion Mass Spectrometry
Dynamic SIMS	Dynamic Secondary Ion Mass Spectrometry
Raman	Raman Spectroscopy
EDS	Energy Dispersive X-ray Spectroscopy
AES	Auger Electron Spectroscopy
FE-AES	Field Emission Auger Electron Spectroscopy
EELS	Electron Energy Loss Spectroscopy
APT	Atom Probe Tomography
ppm	Parts per Million
ppb	Parts per Billion
ppt	Parts per Trillion

Figure 1: The spatial and analytical ranges of selected modern nanostructural analysis techniques (after a graphic by Charles Evans and Associates, www.cea.com)

The Australian Microscopy and Microanalysis Research Facility (AMMRF)

Organisation

Established in 2007 under the Commonwealth Government's National Collaborative Research Infrastructure Strategy (NCRIS), the AMMRF is a joint venture between Australian university-based microscopy and microanalysis centres (Figure 2). The AMMRF is a national grid of equipment, instrumentation and expertise in microscopy, microanalysis, electron and x-ray diffraction and spectroscopy providing nanostructural characterisation capability and services to all areas of nanotechnology and biotechnology research.

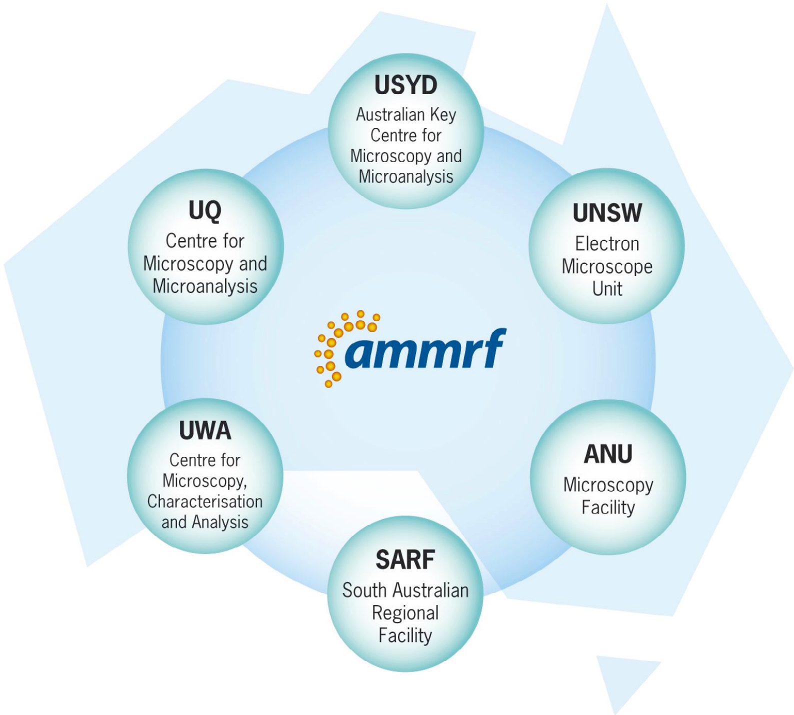


Figure 2: The microscopy centres that form the nodes of the AMMRF

Operating in nodes located in major capital cities with links to smaller units in specialist facilities, the Facility provides access to a vast array of instrumentation. These include widely used optical, electron, x-ray and ion beam techniques and importantly, state-of-the-art flagship platforms that form world-leading capabilities. Such capabilities include pulsed-laser local electrode atom probe, high-throughput cryo-electron tomography, high-resolution SEM and spectroscopy, high-precision ion microprobe and ultra-high resolution TEM platforms.

By combining new flagships with existing capabilities, the Facility offers a complete, modern suite of instruments accessible to all Australian publicly funded researchers on merit basis and a nominal fee schedule. Industry based researchers can also access the facilities for proprietary research at commercial rates.

New South Wales is a major stakeholder in the AMMRF with two of the founding nodes based at The University of Sydney and The University of New South Wales. Moreover, The University of Sydney plays a major leadership role as the Headquarters for the AMMRF. In addition to the two core nodes, linked facility partnerships have also been established with ANSTO and Macquarie University. A third linked facility arrangement with a NSW based research centre is currently being discussed.

Co-investment by the NSW Government in AMMRF through the NSW Science Leveraging Fund is $4M. This funding has been used to provide state-of-the-art “flagship” instrumentation for nanostructural analysis, instrument support engineers to facilitate access to the instruments by all researchers and early career scientists who will drive the application of the instruments in the area of nanotechnology.

The AMMRF works co-operatively with the Australian National Fabrication Facility (ANFF), another NCRIS funded capability in the area of nanofabrication and nanotechnology. A Memorandum of Understanding between the AMMRF and ANFF has formalised the intent of these two facilities to collaborate across capabilities in the areas of business development and best practice in facility management.

AMMRF Benefits to NSW – Infrastructure for Nanotechnology R&D

The NSW based nodes of the AMMRF have made available to the nanotechnology research community and industry a vast network of microscopy and microanalysis platforms. The AMMRF flagship instruments that are of particular importance to nanotechnology researchers are described in the following sections along with the identity of research groups in NSW who are currently using the platforms.

High-resolution Scanning Electron Microscopy (SEM) Analysis Facility at UNSW

This capability combines aberration-corrected SEM, high-resolution electron microprobe and electron back scattered diffraction technology to provide a unique characterisation facility for advanced materials and nanoscience. Research in nanotechnology depends on the ability to create and exploit structures and phenomena on the nanoscale. The high-resolution SEM analysis facility will offer researchers the enhanced spatial resolution for imaging, diffraction and spectroscopy necessary to maintain international leadership in the applied physical and chemical sciences, engineering and nanotechnology.

The types of work that this facility enables include:

- Designing and fabricating nanoscale devices for novel electro-optical systems and photovoltaics.
- Investigating metallurgical problems associated with ferrous extractive metallurgy, diffusion profiles, high temperature oxidation, coke manufacture and so on.
- Developing fine-grained aluminium and titanium alloys for transport applications and thin films for devices and tribological applications.

These instruments represent the first of their kind in Australia. The aberration-corrected SEM combines sub-nanometre resolution with the topographic information of large-scale systems exclusive to this type of microscopy. The use of field-emission sources for X-ray spectroscopy and electron diffraction offers researchers access to chemical, textural and crystallographic data at the sub-micron resolution necessary for advancing research in Australia. Collectively, these instruments present an unparalleled platform for informed design of new devices for harnessing quantum effects in computing and energy conversion and for tailored creation of environmentally friendly industrial catalysts and separation membranes.

Researchers from Australian institutions will make significant use of this facility each year. The majority of these researchers will come from NSW and include users from:

- ARC Centres of Excellence for Quantum Computing, for Advanced Silicon Photovoltaics and Photonics, for Functional Nanomaterials, for Design in Light Alloys, and for Electromaterials Science.
- CRCs for Black Coal and for Advanced Composites.
- Major research groups investigating surface treatments, ferroelectric material, opto-electronic materials, macromolecular polymers, membranes etc.

Industry users of this capability will include those investigating semiconductor devices, advanced electronic equipment, sonar devices, devices for the hearing impaired, steel production and mining.

Wide-field-of-view Laser Atom Probe at The University of Sydney

This instrument extends The University of Sydney's leading capabilities in atom probe tomography - established under the NANO-MNRF - through provision of a wide-field-of-view, pulsed-laser atom probe, which will open up this powerful technique to a large variety of new materials.

Many scientific and technological challenges require a better understanding of structure-property relationships in materials at the atomic scales. The range of these challenges is highly diverse: they include design *at the atomistic level* in advanced alloys such as the light metals and new steels; magnetic multilayers, nanowires, quantum dots and other quantum structures such as spintronic systems, doped semiconductor devices such as Q-bits and ceramic fuel cells. Atom probe tomography is without peer as a tool enabling the microscopic 3-D mapping of the location and chemistry of all elements of the periodic table, providing unique insights into many scientific and engineering challenges. However, the present, voltage-pulsed systems are substantially limited to conductive materials such as alloys and some semiconductors. The new pulsed-laser atom probe allows the analysis of materials of very low conductivities, which means that studies involving semiconductors, ceramics and polymers will become possible.

Examples of the research that this new platform will enable, include:

- Opening up entirely new research fields such as experimentally based materials informatics.
- Investigating the structures of interfaces within nanostructured and nanocomposite advanced ceramics that exhibit dramatic improvements in toughness and other properties.
- A stretch goal for this initiative will be to develop new methodologies to apply this powerful microscopy approach to organic and biological materials.

The laser-based platform will greatly expand the types of materials available for 3D atomic-level analysis to include ceramics, semiconductors, organics, glasses, oxide layers, and even biological materials. The wide-field-of-view enables larger datasets (many tens-of-millions) to be captured than the current-generation local electrode atom probe, while the system also offers an increased mass resolution and a better signal to noise ratio. This is essential for design in materials that rely on subtle atomic interactions.

Major users of the atom probe platform will come from the ARC Centres for Excellence Quantum Computing and for Design in Light Alloys, as well as from universities including The University of Sydney, The University of New South Wales, Wollongong University and Monash University. Industry users include those engaged in semiconductor fabrication, steel and other alloy producers.

Nanotechnology research in NSW is undertaken in a variety of Centres of Excellence, CRCs, university departments, various CSIRO Divisions and ANSTO. Some of these were highlighted previously when describing AMMRF Flagship capability. Current nanotechnology fields of research in NSW that currently benefit from the AMMRF include:

Smart Polymers and Composites: advanced microscopy and microanalysis is critical in device development and in the structural characterisation of nanocomposites, where interfacial properties become drivers of bulk behaviour. Leading groups in this area come from the ARC Centre of Excellence in Electromaterials Science, led by Federation Fellow Professor Gordon Wallace, the ARC Centre of Excellence in Functional Nanomaterials, the ARC Centre of Excellence for Free Radical Chemistry and Biotechnology, the ARC Key Centre for Polymer Colloids.

Nanoporous Materials: Microscopy and microanalysis techniques such as high-resolution electron tomography and aberration-corrected SEM and TEM are necessary for the characterisation of the 3D structure of these systems and the active molecular or atomic sites that provide catalytic functionality. Researchers based at The University of Sydney in this area include Federation Fellows Professor Thomas Maschmeyer, working on nanostructured materials for sustainable industrial processes and Professor Cameron Kepert, creating new microporous molecular frameworks with unique properties.

Light Alloys: State-of-the-art microscopy and microanalysis techniques such as aberration-corrected TEM, atom probe tomography and focused ion beam platforms allow metallurgists to first characterise and then design new alloys at the atomic scale. This type of research is essential for Australia's competitive edge not only in the science of advanced materials but also in high-value-added export markets. Nodes of the ARC Centre of Excellence in Design of Light Metals are located at The University of Sydney and University of New South Wales.

Quantum Technologies: The production of these devices, which exploit the unique properties offered by quantisation at the nanoscale, entails the controlled placement of atomically thin films, individual molecules and even single atoms. Though the formation of these structures pushes fabrication methods to the edge, the demands on characterisation are no less severe. Advanced microscopy and microanalysis are central to the exploration of these nanoscale structures (e.g. high-resolution, and in the future, aberration-corrected, electron microscopies) and, in many cases, are used as integral tools in the fabrication processes (e.g. manipulation by scanned probe or focused ion beam). Australia has world leadership in this area through major research groups that include ARC Centres of Excellence in Quantum Computer Technology and in Quantum-Atom Optics

Photonics and Related Technologies: Modern photonic research focuses on devices such as photonic crystals and arrays, nonlinear photonic systems and microstructured optical fibres with future visions for data processing and computation using photons rather than electrons. Microscopy and microanalysis play a central enabling role in such research through provision of capabilities for structural and chemical characterisation as well as direct manipulation. Next-generation platforms are necessary to allow continued reduction in the size and continued increases in the complexity of photonic systems.

Much of Australia's leadership in this area is within the ARC Centres of Excellence for Ultrahigh band width Devices for Optical Systems (CUDOS) and for Advanced Silicon Photovoltaics and Photonics.

Understanding the Molecular Basis of Disease: Modern microscopy techniques are indispensable tools to this research for understanding: the dynamics of cells; the pathways of cell signaling, transport mechanisms, regulation and cross-communication; and processes of cell death. For instance, the combination of live-cell fluorescence microscopy and subsequent electron tomography analysis on the same vitrified cells is providing unprecedented insights into membrane processes, cell division and cell survival. Research into nanoscale processes is performed at numerous medical research institutes in NSW and around Australia.

Nanostructured Biomaterials and Medical Devices: Despite the remarkable regenerative capacity of the human body, there are times when the extent of damage from injury or disease is too great for complete self-repair. In these instances, advances in biomaterials and medical devices provide at least partial solutions that can extend the duration of life and improve the quality of life. Advanced microscopy and microanalysis are important enabling tools in these areas. For instance, a comprehensive dualbeam platform allows porous bone replacements to be sectioned by focussed ion beam extracted with nanomanipulators and viewed by field-emission scanning transmission electron microscopy. Environmental scanning electron microscopy combined with in-situ vibrational spectroscopy allows imaging and spectral analysis under near-physiological conditions; atomic force microscopy adds the ability to probe and manipulate samples under such conditions.

Biosensors and Diagnostic Tools: High-throughput, automated confocal microscopy is used in analysis of microarrays for detection of cells, genes, proteins or DNA. Of course, it is not possible to design and characterise the substrates and interfaces of biosensors and diagnostic platforms without scanning probe microscopy, and cross-sectional transmission electron microscopy. Increasingly, bio-coated scanned probes and near-field scanning optical microscopes form part of the actuation mechanisms in new biosensors.

Drug Discovery and Nanoscale Delivery: Cryo-electron tomography enables, for example, the investigation of liposomal formulations and the assessment of the encapsulation efficiencies of novel anti-cancer drugs within those biocapsules. Scanning and transmission electron microscopies are essential for the design of porous-nanoparticle carriers or magnetic nanoparticles for targeted drug delivery and other therapies.

Environmental Sciences: The variety of microscopy and microanalysis platforms available in the AMMRF is enabling solutions to be found to various problems facing the environment today. Nanoscale characterisation supports projects in the areas of management of biodiversity, effects of climate change, pollution and remediation minerals and other resource extraction and processing. Research centres in NSW are linked with others throughout Australia to tackle these projects that have a far reaching national impact.

In addition to enabling world-class research outcomes for research centres in NSW, scientists and engineers within the AMMRF also conduct nanomaterials research projects. These projects include:

New Generation Steel Products: Strip casting is a method of producing steel strip directly from liquid steel, which holds the potential for unique steel properties. In partnership with BlueScope Steel Ltd, advanced microscopy techniques are being applied to investigate and optimise the effects of microalloying additions on nanoscale microstructure in new strip cast steels. The work will use atom probe tomography and other microscopy techniques to elucidate the influence of nanoscale precipitation to engineering behaviour during thermomechanical processing.

Quantitative Structure-Property Relationships in Advanced Aluminium Alloys: Aluminium alloys are the most successful and widely used of the light alloys in modern engineering. Nevertheless, the prospect of designing the new alloys at the nanoscale offers the chance for further enhancements in property profiles, thereby creating entirely new applications. This major effort is a core part of the research of the Centre of Excellence for Design in Light Metals.

Structures and their Effect on Deformation Mechanisms in Nanostructured Materials Processed by Severe Plastic Deformation: A current challenge for material scientists is the development of light structural alloys that possess both high strength and high ductility. This combination of properties seems possible to attain in nanostructured materials. Consequently, the aim of this project is to use microscopy to develop new insights into the fundamental mechanisms of deformation and how these relate to nanostructure.

New Approaches to Reconstruction and data analysis in Atom Probe Tomography: An ultimate in microscopy would be the possibility of imaging every atom or molecule in a specimen and identifying their location and species. Atom probe tomography brings us closer than ever to this ultimate, generating atomic-scale 3-D data sets with the very high (ppm) chemical sensitivity. Whilst the technique is very powerful and already provides unique insights into materials, there are aberrations and reconstruction artefacts inherent in current data sets. This project will combine novel experimental methods with computer simulations and aims to reduce or eliminate these problems to advance this microscopy technique into a new realm of resolution.

Atom Probe Tomography of Less Conductive Materials: The need for high electrical conductivity has tended to limit the application of atom probe tomography to metals, alloys and highly doped semiconductors. The development of laser-assisted atom probes has the potential to open up this technique to previously inaccessible materials, such as ceramics, polymers, composites and even biological systems. This project aims to meet the new challenges associated with specimen preparation and data reconstruction and analysis in low-conductivity materials.

Microscopic Origin of Ferromagnetism in Spintronic Materials: High-quality dilute magnetic semiconductors are needed for spintronics, the next generation of electronic systems that will use the magnetic spin, rather than charge, of electrons for computation and information storage. In this project, we will employ atom probe, electron microscopy and other techniques to understand the microscopic origin of ferromagnetism in these materials so as to direct the fabrication of high-quality spintronic systems.

Nanotube Nanothermometers – Synthesis, Characterisation and Application: A carbon nanotube (CNT) filled with a low-melting-point metal such as gallium (Ga) creates a nanothermometer that allows temperature measurement at the nanometre scale. Through the use of transmission electron microscopy, this project will focus on characterisation of the nanothermometers and the oxidation behaviour of Ga confined in nanotubes.

AMMRF Benefits to NSW - Industry

The AMMRF currently works with a broad range of industry partners on nanotechnology projects. This includes large-scale industry and SMEs with the bulk of clients currently in the SME category. The industry sectors serviced include mining, advanced materials, biotechnology, manufacturing, semiconductor, chemical, health and medical. Current industry clients engaged with The University of Sydney and University of New South Wales nodes include Silverbrook Research, Peregrine Semiconductor Australia, Bluescope Steel, Cochlear Ltd, Ventracor Ltd, Eiffel Technologies, Wattyl and Lincoln Electric Australia.

The nature of the support can be based on fee for service testing analysis services or strategic R&D partnerships. Projects with BHP Billiton and Bluescope Steel receive funding from the ARC Linkage Project scheme.

Public Education and Outreach

The AMMRF is aware of the importance of the potential societal implications of nanomaterials technology and the need to educate the Australian public about the value of nanomaterials.

Education will assist greatly in public acceptance of nanotechnology and the development of sustainable nanotechnology industries in Australia.

Education and outreach programs will increase public awareness of the importance and relevance of nanomaterials and technology to Australia's continued prosperity. This will be achieved through mechanisms including:

- Outreach to industry leaders and training courses for technical/R&D staff;
- Development of Postgraduate courses in nanomaterials and advanced microscopy and microanalysis within the nodes of the AMMRF;
- Short-courses and tours of the AMMRF for secondary students and school teachers in science and related disciplines to increase the awareness of nanomaterials;
- Mobile seminars and demonstrations, including telemicroscopy, to schools using the successful "Microscopes on the Move" model developed by The University of Sydney

Recommendation 2: The NSW State Government develops and fund education activities that will assist greatly in public acceptance of nanotechnology and the development of sustainable nanotechnology industries in Australia.

Safety, Health and Environmental Issues Related to AMMRF Activity

Projects to be performed within the nodes of the AMMRF seeking to characterise the nanostructure of materials or investigate molecular scale interactions must meet the OH&S requirements of the nodes. Particular OH&S needs relating to a project are identified at a "new user meeting" (NUM) between potential AMMRF users who are able to discuss their intended project with technical and academic staff. A risk assessment is performed at that time. Generally nanomaterials that are being characterised using advanced microscopy and microanalysis tools are safe to handle and offer no exposure threat to the operator of instruments or the researcher.

The large range of microscopy and microanalysis platforms available in the AMMRF is well suited to nanometrology. The AMMRF has been engaged in discussions with the National Measurement Institute to determine how the facility may assist the emerging nanometrology project within the NMI. The platforms available can be used in the development of testing standards and protocols and infrastructure is available for the provision of testing services to meet regulatory processes that may emerge for the nanotechnology industry.

Gaps in NSW Microscopy and Microanalysis Capability for Nanoscale Characterisation

Next generation technology, such as time-resolved aberration-corrected transmission electron microscopy (TEM) will be available soon. Australia, and particularly NSW, is well positioned to be an early adaptor of this exciting technology. Time-resolved aberration-corrected TEM offers the ability to track chemical reactions, materials transformations, and other temporal phenomena at the atomic scale, providing unprecedented information for, e.g. designing green catalysts for industry and ultra-strong, ultra-light alloys for transport systems. The cost of such an instrument is of the order of $7,500,000.

Also noteworthy is the fact that atom probe tomography continues to develop at a great rate of innovation and it is essential to continue our leadership momentum in this field. It is the strong view of the AMMRF that there are not sufficient instruments in NSW for focussed ion beam or dual beam instruments capable of nanoscale patterning and milling as well as imaging. The current nodes of the AMMRF both have acute demand for this technology.

The University of Sydney node of the AMMRF provides an ideal location in which to install such an instrument, taking advantage of existing user access networks to ensure that this leading edge platform is fully utilised by the research community within NSW and Australia. The AMMRF provides the significant resources in the area of specimen preparation, instrument training, experienced practitioners and scientists with track-record to ensure that a new leading edge capability of this type benefits nanotechnology researchers and will place NSW as a world leader in time-resolved aberration-corrected TEM.

The University of New South Wales node of the AMMRF provides an ideal location for analytical scanning and transmission electron microscope FIB tools. Like the Sydney node, growth in demand for the University of New South Wales facilities is such that it is not matched by, e.g., ARC infrastructure support alone. Indeed, continued reliance exclusively on ARC LIEF funding would rapidly open major capability gaps that we feel the state government can play a major role in bridging.

On-going costs would need to be met for this new facility including salaries of positions created to support the instrument and establish an active portfolio of research projects clustered around the facility. Salary costs and investment in next-generation capital infrastructure must be met from:

- second-generation NCRIS-type schemes or other Federal Government arrangements for infrastructure funding,
- further contributions from host institutions, and
- future State and Federal Government grant schemes – depending on the conditions of those schemes at the time.

Recommendation 3: Australia must continue to invest in advanced microscopy and microanalysis infrastructure because the current and future challenges for science and technology all exist at the limits of spatial resolution and chemical sensitivity of many characterisation techniques. Future investment in time-resolved aberration-corrected transmission electron microscopy (TEM) and focussed ion beam platforms would benefit nanotechnology R&D and fill a gap in capability in NSW.

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