ARC Centre for Functional Nanomaterials

NanoMatters

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The Newsletter of the ARC Center for Functional Nanomaterials

Welcome to the Premiere Edition

Welcome to this premiere edition of Nano Matters - the Quarterly Newsletter of the ARC Centre for Functional Nanomaterials.

The Centre was established in November 2003 under the Australian Research Council's Centre of Excellence Program. The Centre aims to become a world class centre of excellence leading research in nanomaterials in particular functional nanomaterials. Our research focuses on functional nanomaterials having properties that are useful in processes such as adsorption, ion-conducting, separation, catalysis, biomaterials and biosensing.

The Centre aims (1) to carry out world-class research at both fundamental and applied levels into the synthesis, characterisation and application of various nanomaterials; (2) to provide first rate research training contributing to the growth of Australia's human capital; and (3) to establish close research linkages with leading positioning Australia as a world leader in this emerging field.

The programs will lead to innovative techniques and technologies that will underpin new materials and products for applications in clean energy, environmental, and health care industries.

2004 has been a very busy year for the Centre researchers, setting up research projects, recruiting, and continuing performing the research activities at a high level. I have the pleasure to introduce the first issue of this newsletter, highlighting some of our research advances and other research activities and events. I would like to call upon all chief investigators to contribute short write-ups to highlight research progresses and news items to share with our readers. Any comments and feedback from readers would be also gratefully welcome.

Professor Max G.Q. Lu
Research Director

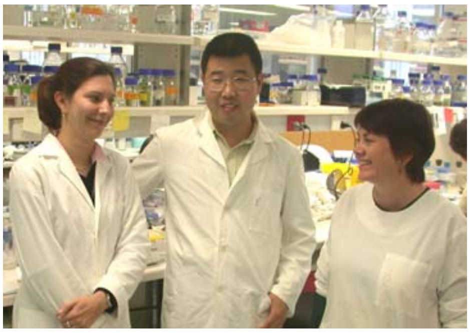
May I take this opportunity to wish all a Merry Christmas and Happy New year.

Inside this issue:

Nano-vehicles for drug delivery

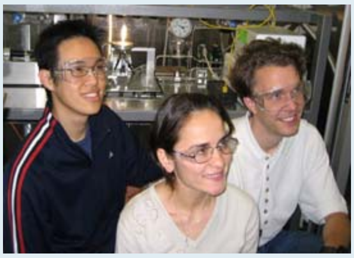
In the classic 1966 science fiction movie *Fantastic Voyage*, a team of doctors and scientists, along with a submarine, were miniaturised so that they could be injected into a dying man's bloodstream and perform surgery from inside his body to save his life.

What was a complete fantasy almost 40 years ago could now be considered surprisingly close to reality as scientists are now combining biology with nanotechnology to produce tiny 'nano-vehicles' that can easily enter cells and deliver a pay-load of DNA directly inside the cell. Once in the cell, this DNA can then be used to direct the cell to manufacture disease-fighting proteins *in-situ*. It would be like setting up an incredibly small pharmaceutical factory to manufacture medicines exactly where they are required. Researchers Dr Gordon Xu and Professor Max Lu from this Centre in collaboration with Professor Perry Bartlett, Dr Helen Cooper and Dr Tara Walker from the Queensland Brain Institute are working on a project developing nanoparticles of layered double hydroxides (LDH) as nano-vehicles for just this purpose.



Dr Helen Cooper, Dr Gordon XU and Dr Tara Walker

To deliver the DNA inside a cell, such nano-vehicles have to firstly get through the cell membrane. Cell membranes are negatively charged and so the nano-vehicles are made with a positive charge that allows them to pass through the cell membrane quite easily. Once in the cell, the vehicle simply dissolves away and releases the DNA to do its work.



Mr Wey Yang, Dr Donia Beydoun and Dr Lutz Maedler

Bringing the flame to the ARCCFN @ UNSW

A Flame Spray Pyrolysis (FSP) reactor, the first of its kind in Australia, has recently been lit at the newly established ARC Centre for Functional Nanomaterials, UNSW. This achievement is the result of a combined effort of the young research team of Dr. Donia Beydoun, her PhD student Mr. Wey Yang Teoh, and Mr. Phillip McAuley from the School of Chemical Engineering and Industrial Chemistry, as well as Dr. Lutz Maedler from the Particle Technology Laboratory, the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland.

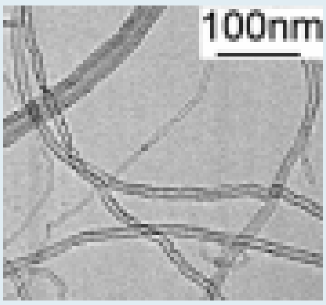
Flame spray pyrolysis (FSP) is a technology for preparing particles of closely controlled properties down to the nanoscale, for numerous applications ranging from catalysis, sensors to dental fillings.

The UNSW team's interest is in making functional nanoparticles for environmental and energy applications, specifically photocatalysts for the removal of organic contaminants and heavy metals from water, and Fischer Tropsch catalysts for gas to liquid fuel conversion.

FSP reactors are part of an expansion of particle flame synthesis, an established industrial process, from simple oxides to more complex nanoparticles. In FSP reactors, the liquid precursors are sprayed into the flame. The particles are formed by the rapid combustion and disintegration of solution droplets as they enter the high-energy flame. Its technology edge originates from its flexibility, its ability to utilize a broad range of liquid precursors and their mixtures, and most importantly its ability to be scaled up. In short, FSP makes it possible to produce tailored nano-sized particles of complex structures (the combinations are endless!) in large scale.

The idea to bring this new technology to UNSW was set into action in 2001 when Dr. Beydoun visited the Particle Technology Laboratory explore the use of aerosol technology for the synthesis of improved functional photocatalysts. Mr. Wey Yang Teoh spent his research attachment with PTL in Switzerland. During this time he was trained on the use of the flame spray reactor under the supervision of Dr Lutz Maedler to prepare TiO2 and Pt-TiO2 nanoparticles for photocatalysis applications.

Dr. Maedler has recently visited the UNSW team, and was there for the initial test runs. The great news is that the tests have gone well, and the technology has been successfully transferred from ETH to UNSW, thanks to the inspiring international outlook of both research teams.



TEM image of single walled carbon nanotubes

Carbon nanotubes for hydrogen storage

Developing single-walled carbon nanotubes (SWNT) with hydrogen storage capacity to meet the 6.5 wt% target set by the U.S Department of Energy (DOE) is attracting a great deal of research interest worldwide. There is much interest in the carbon nanotubes as it is empirically estimated that SWNTs could potentially store 10 wt% hydrogen at 273K. The hydrogen uptake in currently available carbon nanotubes is near 4 wt%, well below the 6.5 wt% target.

Carbon nanotubes are closely related to (but also subtly distinct from) nanocrystallite graphitic systems. We know from our computational and experimental studies of carbon gasification that most of the chemical activity in nanocrystallite graphitic systems occurs either (i) at the edges of planes or (ii) at defects within the planes. These new findings are in contrast with earlier theoretical approaches to hydrogen uptake which assume physisorption or chemisorption along the regular walls of the nanotubes (these existing models fail to reproduce experimental results). So far, it has been proposed that the high storage capacity is due to the hydrogen entering the tubes through the open ends of the nanotubes and being stored within the tube, rather than in the interstitial spaces. While a SWNT is 200-500 nm long, it is only 1-2 nm in diameter, this precludes molecular free diffusion and may mean Knudsen diffusion is limited. The main transport mechanism is therefore likely to be through surface diffusion.
nanotubes.

Synthetic Bone-Like Nanomaterials

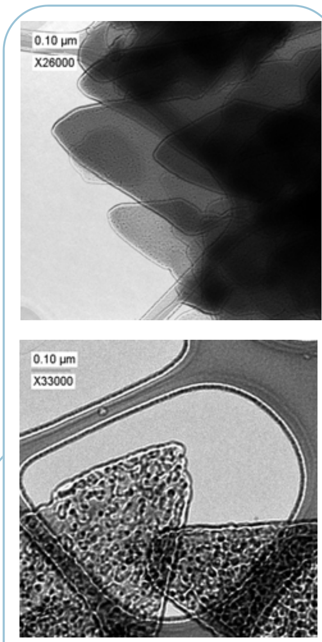
As the population of the industrialized world ages, the number of hip fractures due to osteoporosis is projected to triple to 6.3 million by 2050. In Australia, osteoporosis leads to more than 1.5 million fractures annually causing permanent disability, loss of independence or even death.

Bone comprises bundles of collagen fibrils, which incorporate a nano-crystalline mineral phase, similar to synthetic apatite containing carbonate. Healthy bone is continually undergoing remodeling from the opposing action of osteoblast (bone building) and osteoclast (bone remodelling) cells. If the balance is disturbed and the bone resorption is faster than new bone formation, the bone density decreases leading to osteoporosis.

It is well-known that in the body, apatite is a bioactive material that promotes bone formation rather than bone resorption. ARCCFN researchers at the University of Western Sydney, Prof. Michael Wilson and Drs. Adriyan Milev and Kamali Kannangara have been successful in developing a novel synthetic bone-like material that mimics the chemistry and morphology of biogenic bone materials. This material may be used as a nano-sized additive for synthetic composite bone graft materials with enhanced biocompatibility and performance.

The method stems from a world first discovery of a self-assembly approach to the formation of apatite powders that involves the formation of a nanosized (~1.3 nm) lamellar calcium-acetate-phosphonate apatite precursor and then separating the individual lamellae into platelets with a very high aspect ratio that resembles natural apatite. Because this synthetic apatite closely resembles the chemical and physical properties of biological apatites, it can be recognised by the bone osteoblast cells and so may reduce implant integration from four weeks to one week. This has a remarkable potential benefit for patient treatment.

This same approach to creating synthetic apatite can also be used to create self-assembling apatite coatings on surgical metallic implants by the spontaneous formation of continuous two-dimensional layers. This biomimetic approach could lead to the next generation of biologically and structurally realistic bone analogues for orthopaedic applications. The economic benefits from the development of effective and efficient prosthetic implants will be enormous, both in terms of the product itself and the savings in terms of the medical aspect.



TEM images showing several lamellae of the precursor and the resulting bone-like apatite.

"In Australia, osteoporosis leads to more than 1.5 million fractures annually"

Nanomaterials to help bad backs

Most people would know of at least one person who has been affected by a condition known as intervertebral disc degeneration. You will have heard of phrases such as *slipped, bulged or herniated* discs I'm sure, but what do they mean, and in severe cases, how can they be fixed?

Intervertebral disc (IVD) degeneration is an important social and economic problem. The human IVD consists of a "gel-like" nucleus pulposis, surrounded by a highly-anisotropic and "composite-like" annulus fibrosis.

Upon disc degeneration, a weakening of the annulus fibrosis occurs and quite often this results in the formation of lesions (tears) and eventual herniation of these structures. This can cause severe pain and physical incapacitation as the herniated structures impinge on the spinal nerve.

In a healthy IVD, this amazing and complex structure can withstand the high loads acting on the spine in everyday life, while giving the vertebral column its stability. The flow of water in and out of the disc structures plays an important role in "damping" and protecting the spine against high impact loads, while still allowing for flexible and supple movement during lower impact activities.

How can Nanomaterials help?

Removal of the IVD and "mechanical fusion or fixation" of the joint was, and still is the most commonly-practiced intervention.

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Nanocomposite biomaterials offer potential solutions for new generation spinal implants

ARC Centre for Functional Nanomaterials

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About The ARC Centre for Functional Nanomaterials

The ARC Centre for Functional Nanomaterials was established in November 2003 under the Australian Research Council's Centre of Excellence Program (Reserved Round). The Centre aims to become a world class centre of excellence with leading Australian researchers in nanomaterials.

The Centre has its headquarters at The University of Queensland in Brisbane, and a NSW/ACT Node based at The University of New South Wales. It brings together leading researchers from four Australian Universities with the Centre's Chief Investigators coming from The University of Queensland, The University of New South Wales, The Australian National University and The University of Western Sydney. The Centre also brings together Partner Investigators from four CSIRO Divisions as well as from IBM's Almaden Research Centre and Washington University in St Louis.

The Centre's research programs focus on the novel synthesis, characterisation and applications of functional nanomaterials such as nanoparticles, nanotubes, thin films, and nanoporous and nanocomposite materials. Such materials are constructed by self-assembly at the nanometer scale (1-100 nm) possess improved properties and unique functionalities such as high surface area, nanosize and quantum confinement effects, ordered porosity, and high adsorbing and sensing abilities. Thus, they are ideal materials for adsorbents, catalysts, sensors, fuel cells, and battery systems. They are also attractive for biotechnology applications due to the controlled effectiveness of protein-material, cell-material, and tissue-material interactions.

In The News

Dr Andrew Dicks appeared on the ABC's Catalyst programme where he discussed hydrogen and fuel cells as an alternative to fossil fuels.

Prof. Mick Wilson and *Prof. Matt Trau* were interviewed on Radio National's Background Briefing programme on Nanotechnology.

Congratulations

Congratulations to Centre Research Associate, Dr. Donia Beydoun who has recently won a prestigious Humboldt Fellowship.

As part of the fellowship, Dr. Beydoun will be working on the design of Metal-TiO_2 Photocatalysts under Prof. Detlef Bahnemann, the head of the Photocatalysis and Nanotechnology Laboratories in the Institute for Technical Chemistry at the University of Hannover, Germany.

Nanomaterials to help bad backs

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However, this has been shown to lead to other problems due to the loss of mobility and transferal of stress to other areas. Of more interest recently has been the growing development and use of artificial intervertebral disc devices (AIDS). One of the more promising designs employs a biomedical polyurethane elastomer sandwiched between two porous cobalt-chrome alloy plates. This device is shown below together with X-ray images of the device in place in the cervical (neck) spinal region showing the good range of movement possible due to the flexible, biocompatible polyurethane.

This such device is at this stage limited to human trials only in the neck, where loads are much lower than, say, the lumbar region. ***There is a great need to develop a device with the mechanical performance and anisotropic structure and behaviour of a natural IVD.***

In the ARCCFN we have begun work on nanocomposite polyurethane materials incorporating inorganic and carbon nanotube nanoreinforcements. Our ultimate goal is to produce highly-oriented, high-tenacity fibres to use as efficient reinforcing elements in these complex structures.

X-Ray showing the artificial intervertebral disc device in position.