CSEM's

Materials Monthly

August 2004

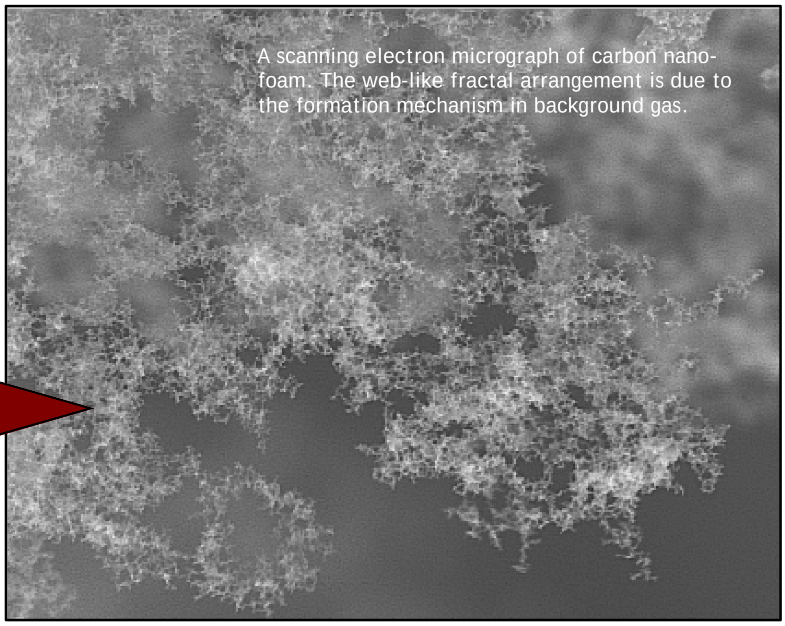
Making materials matter

Winner of the Engineers Australia Eureka Prize for Engineering Journalism

Pulse built foam

Pulsed laser deposition is proving to be a valuable tool in building exciting and novel materials from the bottom up.

▲▲ Nathan Madsen with samples of carbon nanofoam—a material so new and so novel that applications haven't been thought up for it yet. Knowing how to create it with ultra fast laser pulses is half the challenge.



A scanning electron micrograph of carbon nano-foam. The web-like fractal arrangement is due to the formation mechanism in background gas.

It looks just like black soot. Actually, that's what it is – a fine powder of carbon; but this soot might be the most amazing high-tech soot you'll ever read about.

Scrape it up and you'll immediately notice it's incredibly fine and light. To discover how fine you'll need an electron microscope because the particles that make it up are only a few nanometres in diameter.

However, there's more to this soot than just being light. The fine powder seems to jump around as you gather it together. This soot is picking up electric charge. But the biggest surprise is that when you hold a magnet to it, some of the soot will cling to it. This soot has paramagnetic properties – very unusual for carbon, which is generally diamagnetic.

So what is it? It's been dubbed carbon nanofoam by its creators. It has a signature of a structure known as schwarzite - hyperbolically curved graphitic sheets made up of seven (heptagons) and eight membered (octagons) rings of carbon atoms as opposed to conventional six membered rings (hexagons). It's one of the lightest known solid substances (with a density ranging from as low as 2 mg/cm3 up to 20 mg/cm3) and it's produced by pulsed laser deposition.

A smarter way to pulse

Pulsed laser deposition (PLD) involves firing a high-intensity, pulsed laser beam at a target in a chamber that's either evacuated or filled with a specific gas such as argon, oxygen or nitrogen. The laser beam causes the target material to vaporise (or ablate) into the chamber. A substrate to be coated is placed in the path of the laser-produced plume, and the vapour clings to its surface, forming a thin layer of the ablated target material.

PLD has been around for a while however researchers at the ANU Laser Physics Centre (at the Research School of Physical Sciences and Engineering) have significantly improved the process by decreasing the length of each laser pulse and increasing the number of pulses. Traditional PLD fires laser pulses that last around 10 nanoseconds (or 10 billionths of a second – a billionth = 10^{-9} seconds) and firing it repeatedly at the target at a rate of around 10-100 times per second. The ANU laser physicists, led by Federation Fellow Professor Barry Luther-Davies and Dr Andrei Rode, are using much shorter pulses (measured in pico, 10^{-12}, down to femto, 10^{-15}, seconds) with a much higher repetition rate (a million times per second). The new process is referred to as ultra-fast PLD.

The consequence of using shorter pulses fired more frequently is that fewer atoms are vaporised per pulse but more target

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THE AUSTRALIAN NATIONAL UNIVERSITY

Pulse built foam

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material is vaporised overall because the pulsed beam hits the target more often. The result is a faster deposition rate with a much more even film. The technique is up to 100 times faster than conventional PLD and produces a film of much higher quality. And, because the vaporisation can be relatively easily controlled, the nature of resultant film can be easily modified.

Building new materials

Not only is the technique promising a revolution in thin layer deposition, the laser scientists are also producing some amazing materials with the technique. Among several novel materials that have been produced is carbon nanofoam, formed when Ultra-fast PLD is used to evaporate graphite in an inert atmosphere of argon.

"The original aim of using ultra-fast PLD to evaporate graphite was to see if it could be used to create carbon nanotubes," says Nathan Madsen, a doctoral student working on the technique. "What we got instead was a totally new form of carbon with a range of properties that had never been seen before."

"It's still believed that ultra-fast PLD could have a major role in building nanotubes however we are yet to learn how to tweak the system to modify various aspects of the resulting materials."

Tweaking the system

Nathan has been studying the process of ultra-fast PLD for over a year now and has only just started to produce samples of carbon nanofoam.

"It's not a matter of simply switching on the machine and nanofoam comes out one end," says Nathan. "You need to understand the process and be able to modify the various parameters that affect the material you're forming such that you gain control over the form of the end material. Otherwise it's not really science."

The variables that need to be considered include the pressure of gas in the chamber where the ablation takes place, the type of gas used and the frequency and duration of the laser pulses used to ablate the material.

"Each variable can totally change the nature of the resulting material," says Nathan. "Change the background pressure, for example, and it changes the packing of the particles that make up the carbon foam. The higher the pressure, the more densely packed the material."

Some of the variables can be changed by turning a dial, others require the construction and integration of completely new hardware and software.

Tubes to foam and back to tubes

"At the end of the day, it's not just about making more carbon nanofoam," Nathan explains. "It's about understanding what you have do to the ultra-fast PLD system in order to produce a specific change. Because if you can manipulate the system well enough to be able to control the properties of the materials you're producing then you're well on the way to developing a valuable tool for nanotechnology – a system that can produce significant quantities of materials with made-to-order properties based on their molecular compositions."

Why is it magnetic?

Researchers have concluded that the observed novel magnetic behavior is an intrinsic property of the carbon nanofoam and can be traced to its complex microstructure. Namely, carbon atoms in the foam forms heptagon structures, 7-corner, 7-edge polygons that have an unpaired electron, one that does not form a chemical bond and has a magnetic moment which may lead to the magnetism. Researchers also have preliminary indications that the novel magnetic behavior also occurs in another nano-compound made of boron and nitrogen, two other elements that are ordinarily non-magnetic.

Nathan and some of the apparatus used to build carbon nanofoam. ▶▶

"To that end, carbon nanofoam is a great guinea pig material for us. We didn't foresee it in the first place but by studying how it's formed and can be modified using PLD we are gaining tremendous insights on how molecular materials can be built from the bottom up. Short bursts of laser are creating a plumes of atoms which reform into new materials.

"Nanofoam arose out of the quest for carbon nanotubes, but it's more than probable that we what learn from making nanofoam will be invaluable in coming up with new ways to form nanotubes, buckyballs and wide range of other nanoscale materials."

A unique material

However, carbon nanofoam could well turn out to be an important material in its own right because of its range of extraordinary properties. The surface area of the particles that make up the nanofoam single is enormous. A single gram has a surface area of 300-400 square metres. On top of that it's an excellent conductor of heat while possessing extremely low electrical conductivity. And, it's magnetic.

One possible application of the carbon nanofoam is in biomedicine, as tiny ferromagnetic clusters. These could be injected in blood vessels and may significantly increase the quality of magnetic resonance imaging pictures.

It's large surface area means it might also make a good material for storing hydrogen for use as an energy source.

"At this point it's open to speculation what carbon nanofoam might be eventually used for," says Nathan. "It's so new and novel we're only starting to understand its special nature. This really is the beginning of a whole new frontier of nanomaterial science."

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Exploring Materials with ANU

a Future Materials Industry & Research Workshop

At the end of August, the ACT Office of Future Materials ran a major regional workshop at ANU on materials science and engineering in the ACT. Not only was it a dazzling showcase of what facilities and talents are on offer at ANU, it also highlighted some of the amazing equipment and materials research taking place around Canberra.

"Future Materials has a close connection with the ANU," says Ulrich Theden, Manager of the ACT Office of Future Materials. "It was the brainchild of Professor Jim Williams, Director of the Research School of Physical Sciences and Engineering, and the ACT Office of Future Materials is hosted by CSEM.

Prof Ian Jackson discusses earth materials at the workshop

"The first step towards building more effective partnerships with industry is to get materials scientists and engineers in the region to introduce themselves. That's what we set out to do with this workshop and I think we went some way towards achieving that. Throughout the day-long workshop, over 20 of Canberra's top materials researchers made short presentations on what they're working on and what facilities they can offer."

There were presentations from ANU researchers from the Department of Engineering (FEIT), the Electron Microscopy Unit and the Research Schools of Physical Sciences and Engineering, Research School of Earth Sciences and Research School of Chemistry. From around Canberra there were representatives from the Australian Federal Police (Chemical Criminalistics), Australian Transport Safety Bureau, Civil Aviation Safety Authority, the National Gallery of Australia (Conservation Department), Royal Australian Mint (Materials processing), Sustainable Technologies International (Dye Solar Cell Technology), University of Canberra (Cultural Heritage Research Centre), and the Australian Defence Force Academy (Ion Beam Techniques, Advanced Materials).

"This workshop brings together a galaxy of Canberra's top materials researchers," says Dr Zbigniew Stachurski, Director of the ANU Centre for Science and Engineering of Materials, the group that hosts the ACT Office of Future Materials. "We're hoping that industry might make some important links with academia from the workshop. We're also hoping that some productive partnerships between materials researchers might also be formed."

The ACT Office of Future Materials is supported by the ANU, AusIndustry and the ACT Knowledge Fund.

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William Wachsmann explains Future Materials to workshop participants

Workshop quotes

"Future Materials' vision is to become the gateway for industry to materials research and development."
William Wachsmann, Chief Executive, Future Materials

"I love the thrill of a stamping line – the noise, the smell and the excitement. It's fantastic."
Professor Mick Cardew-Hall on visiting manufacturers metal stamping facilities.

"We have one of the largest concentrations of imaging and analysis equipment in Australia."
Dr Sally Stowe, on the ANU Electron Microscopy Unit.

"Resolving the position of atoms from an arms length is like measuring the distance between a cat's eyes on the Moon."
Professor Gottfried Otting from the ANU NMR Facility on the challenge of determining the position of atoms in a molecule.

▲▲ Peter Gordon (ACT Chief Minister's Department) and Ulrich Theden (Manager, ACT Office of Future Materials).

"We don't do drugs in our labs."
Dr Vincent Otieno-Alego from Chemical Criminalistics, Australian Federal Police. Someone from the audience responded by crying: "Good to hear!"

"We're conservative, we don't like new and novel materials that claim amazing performance but which haven't been extensively trialled."
Dr David Villiers from the Civil Aviation Safety Authority on what they look for in assessing safety in planes.

Networking over coffee

"What do we do? We make money."
Dr Prabir De, Royal Australian Mint

"What is materials conservation? It's a mixture of science and the humanities."
Dr Beata Tworek-Matuszkiewics, Conservation Department, National Gallery of Australia.

Firing up on dung

In the last issue of *Materials Monthly* we reported that Tony Flynn from the Department of Engineering, with the assistance of David Goggins, had demonstrated that fires using dried cow dung as fuel were hot enough for long enough to sinter ceramics for use as water filters. The technique is being investigated in the first instance to help East Timorese villagers to produce water filters from local materials. The next step in the process was to do a series of test firings of the ceramics in question.

"It's worked better than we expected," says Tony. "I initially thought we might have to add some medium sized sticks to attain a slightly higher and more sustained firing temperature but, as it's turned out, the dung by itself works beautifully."

The ceramics being produced are porous, a property that has achieved by mixing in organic material such as rice husks, coffee grounds or tea leaves with the clay. The organic material burns away when the ceramic is fired leaving an articulated void space through which water can pass.

"We're running a series of trials to see how long different mixes need to be left in the dung fires to achieve the best results," says Tony. "The fires themselves are excellent little heat producers achieving temperatures up to 1000ºC which can be sustained for up to an hour."

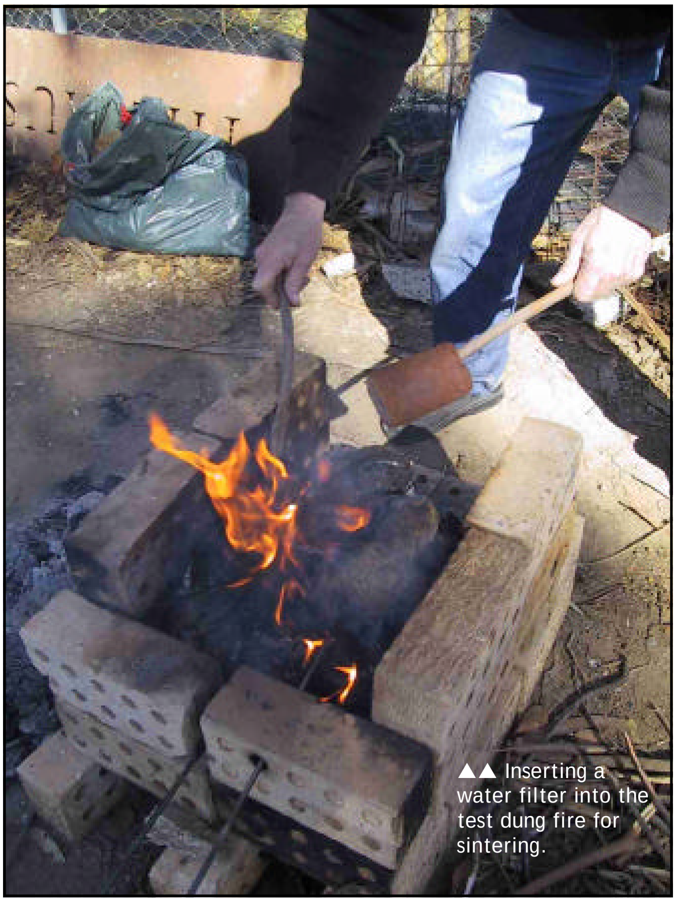
The trials are being conducted in the gardening compound next to Sullivans Creek (right next door to rowing house). And, contrary to what you might first think, burning dried cow dung is not such a malodorous activity.

"Tony invited us over to witness a test firing," says Dr Zbigniew Stachurski, Director of CSEM (which has been a big supporter of the research). "There was a lot of smoke but the smell was pretty similar to a barbeque, slightly earthier but not unpleasant at all. What amazed me was the ease with which the fire could be built and the amazing heat it could generate and sustain – as measured by a thermocouple placed in the fire."

To demonstrate his confidence and mastery in using dung fires, Tony also prepared a hearty breakfast of bacon and eggs for everyone assembled for the test firing. Over breakfast, Tony reminisced about another use of burning dried cow dung.

Tony with two porous water filters sintered in dung fires. The vessel on the left used tea leaves in the mix and took an hour to fire. The vessel on the right used rice husks and only needed 20 minutes. ▶▶

Tony fries eggs on the dung fire. ◀◀



▲▲ Inserting a water filter into the test dung fire for sintering.

"When we were kids we used to use the smoke from burning dried cow dung to keep away mossies. It worked a treat as long as you were covered in smoke. I think our current application has more potential."

"We've demonstrated how effective these fires can be," says Tony. "We've now shown they can produce quality porous ceramics that are excellent at removing sediment from water. The next step is to determine how effective these filters are at removing disease-causing organisms from water.

"We're hopeful they will play a valuable role, and because they can be produced from local materials using extremely low technology, their contribution to improving health in developing countries could be enormous. They can be produced anywhere there's clay and cows—and that's most of the world."

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The proof of the pudding is in the eating. These egg and bacon burgers pass the test.

Three new networks

The ANU has been successful in seeking funding to support three science-related networks through the ARC Research Networks scheme. The scheme is a new program designed to encourage collaborative approaches to research in inter-disciplinary settings.

ARC Research Networks are platforms for generating new knowledge in areas that span traditional disciplinary boundaries. Networks link researchers, research groups and others involved in innovation; nationally and internationally.

The three ANU networks that have successfully sought funding are in the areas of Complex Systems, Nanotechnology and Advanced Materials.

Complex Open Systems Network
Complexity is the common frontier in the physical, biological and social sciences. This Network will link specialists in all three sciences through five generic conceptual and mathematical theme activities. It will promote research into how subsystems self-organise into new emergent structures when assembled into an open, non-equilibrium system. Outcomes will include new technologies and software tools and deeper understanding of fundamental questions in science.
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Australian Nanotechnology Network
The field of nano scale science, engineering and technology (in short nanotechnology) is just emerging and it is predicted to make a major impact in all technologies and areas of society. Australian Nanotechnology Network intends to harness the combined Australian capability to enable Australia to take a leading role in this rapidly growing field.

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Australian Research Network for Advanced Materials
This network will promote interactions that do not usually occur between materials researchers and students across Australia and internationally from diverse disciplines. The scope is broadly based on advanced materials production, processing and properties but focused in four areas, involving: i) innovative structural/functional materials, ii) high-tech IT/communications/sensing materials, iii) materials solutions for manufacturing, iv) materials for a sustainable Australia, and v) emerging materials technologies. Key programs will promote interdisciplinary workshops and early career researcher interactions.

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Awards hat trick for RSC

Research School of Chemistry staff have won three prestigious awards. Professor Martin Banwell was awarded the 2003 Royal Society of Chemistry Industrially-Sponsored Award for Synthetic Organic Chemistry and the Novartis Chemistry Lectureship for 2004. RSC Dean, Professor Denis Evans has won the 2004 Moyal Medal, which is awarded "for distinguished contributions to research in mathematics, physics or statistics".

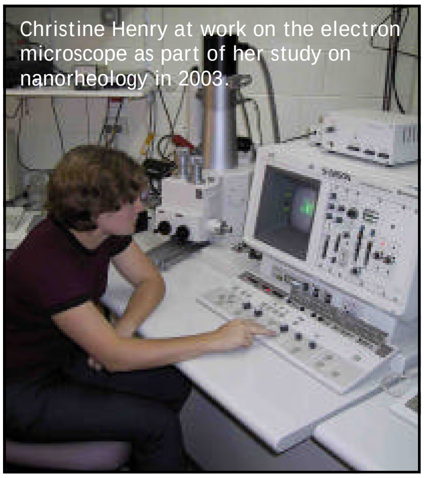
Professor Banwell is Head of Organic Chemistry at RSC. His research focuses primarily on developing new methods for the synthesis of biologically active target molecules. He was awarded the Royal Society of Chemistry prize for the "elegant use of chemoenzymatic methods for the preparation of a wide variety of complex natural products".

Professor Evans research interests include non-equilibrium statistical mechanics and thermodynamics, and he has been involved in the development of nearly all the computer simulation algorithms used in the calculation of transport properties of classical liquids.

The 2004 CSEM Prizes

Yes, it's on again – ANU's only award aimed specifically at encouraging excellence in materials science and engineering at an undergraduate level.

Each year CSEM offers two $2,000 awards for the best undergraduate final year thesis in materials. One award will go to the best thesis in the field of the **'Science of Materials'.** The other will go to the thesis in the field of '**Application of Materials**'.



Christine Henry at work on the electron microscope as part of her study on nanorheology in 2003.

The beauty of the awards is that they don't require the students to go to much additional work to enter. If you're enrolled in a program leading to the award of an undergraduate Bachelor degree at ANU and are submitting your final year Honours thesis this year, you're eligible. All you have to do is submit a copy of your thesis to the Director of CSEM.

In 2002 CSEM Prize for Application of Materials went to Alan Swanson for researching and developing a new form of furniture he's called 'air furniture'. The furniture involves the lamination of thin plywood (plantation-grown hoop pine) onto extruded Styrofoam. The resultant furniture is light, seamless, attractive and incredibly strong. Sachin Doshi received the CSEM Prize for Science of Materials for investigations on semiconductor materials being used in optoelectronic devices. Using a technique known as Deep Level Transient Spectroscopy, Sachin studied the effect of defects in doped gallium arsenide semiconductors. (See the December 2002 issue of *Materials Monthly* for details.)

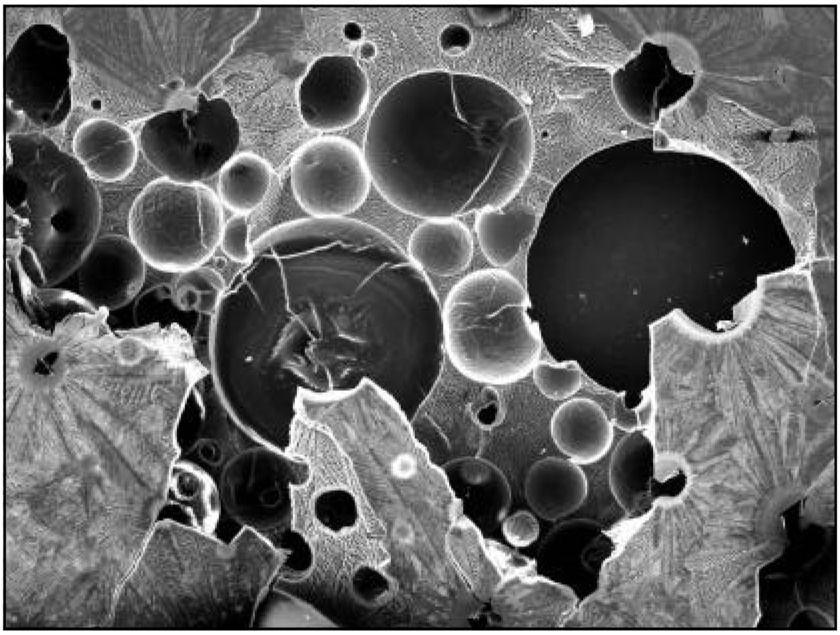
The 2003 CSEM Prizes went to Andrew Walter for best thesis in the area of Applications of Materials, and Christine Henry for best thesis on Science of Materials. Andrew's thesis involved an impact strength analysis of field hockey shin guards. He undertook electron microscope studies of the PVC outer shell and EVA inner shell that make up shin guards, and then modelled their energy absorbing characteristics. Christine's thesis was on nanorheology: the science of rubbing surfaces on a nanoscale. She used a custom-built, modified atomic force microscope to measure both static and dynamic force components concurrently as surfaces approach, and to quantify the degree of boundary slip. She found that the relationship of slip and shear rate is very complex and dependent on the chemical nature of the surfaces as well as the type of relative motion (constant or oscillatory). (See the February 2004 issue of *Materials Monthly* for details.)

Professor Denis Evans presents Andrew Walter with the 2003 CSEM Prize for Applications of Materials.

We have received entries from the Faculty of Science, Faculty of Engineering and Information Technology and the National Institute of the Arts. It'd be great to achieve that coverage again this year.

So, if you know anyone worthy of being considered, please let them know as soon as possible. **Entries close on 30 November.**

More information: http://www.anu.edu.au/CSEM/Prizes.htm



Pick the pic

The challenge put to Dr Roger Heady at the ANU Electron Microscopy Unit was this: "I bet you can't take a picture of bubbles in beer with a scanning electron microscope!" Given that samples in scanning electron microscopes are exposed to a very strong vacuum, this was indeed quite a challenge. However, with a bit of thought Roger realised it wan't insurmountable.

The solution was to freeze a small amount of beer froth in liquid nitrogen and then put the sample in a cryo-stage at -190ºC while observing it in the SEM. The result is the image shown here.

"What's more," comments Roger, "I didn't have to waste the rest of the sample."

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Eureka! We got it!

I rarely lapse into first person in *Materials Monthly* but for this news item it's fitting that I do. Early in 2004, Zbigniew nominated me and *Materials Monthly* for a Eureka Prize in the category of Engineering Journalism (proudly sponsored by Engineers Australia).

Begun in 1990, the Eureka Prizes have grown into Australia's premier national science awards for research and communication. Naturally I was chuffed that Zbigniew nominated me however I never thought we'd be able to compete against the major media players that always contest these awards. I was delighted when we heard I was a finalist, however, I doubted we'd get much further. Consequently, when it was announced I was the winner at the awards ceremony on the 10 August, I almost fell off my chair.

Well, what can I say? Thank you Zbigniew for nominating me, believing in the product and giving me the freedom to develop *Materials Monthly* over time. Thank you to the membership of CSEM who have so warmly embraced *Materials Monthly* and have given me such encouraging feedback. Thank you to Engineers Australia for sponsoring this award and bestowing this honour on a grass-roots publication like *Materials Monthly*. Engineering, and specifically materials science and engineering, needs this type of exposure and acknowledgement. I hope you continue to support this category for many years to come.

Finally, congratulations to the two other ANU Eureka Prize winners: Dr Ken Baldwin who won the Australian Government Eureka Prize for Promoting the Understanding of Science for his role in establishing 'Science meets Parliament', and Steve Clarke who won the Australian Catholic University Eureka Prize for Research in Ethics for his work on tackling the thorny question of informed consent. For pics and more details on these awards see the September issue of ScienceWise (available at http://ni.anu.edu.au/natinst/institute_publications.asp?aaid=60). For the official blurb on all the Eureka Awards see http://www.amonline.net.au/eureka/

The ecstatic editor of *Materials Monthly* receives the Engineers Australia Eureka Prize for Engineering Journalism from Doug Jones, the National President of Engineers Australia.

Stuart Humphreys, Australian Museum

David Salt, Editor, Materials Monthly

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