CSEM's

Materials Monthly

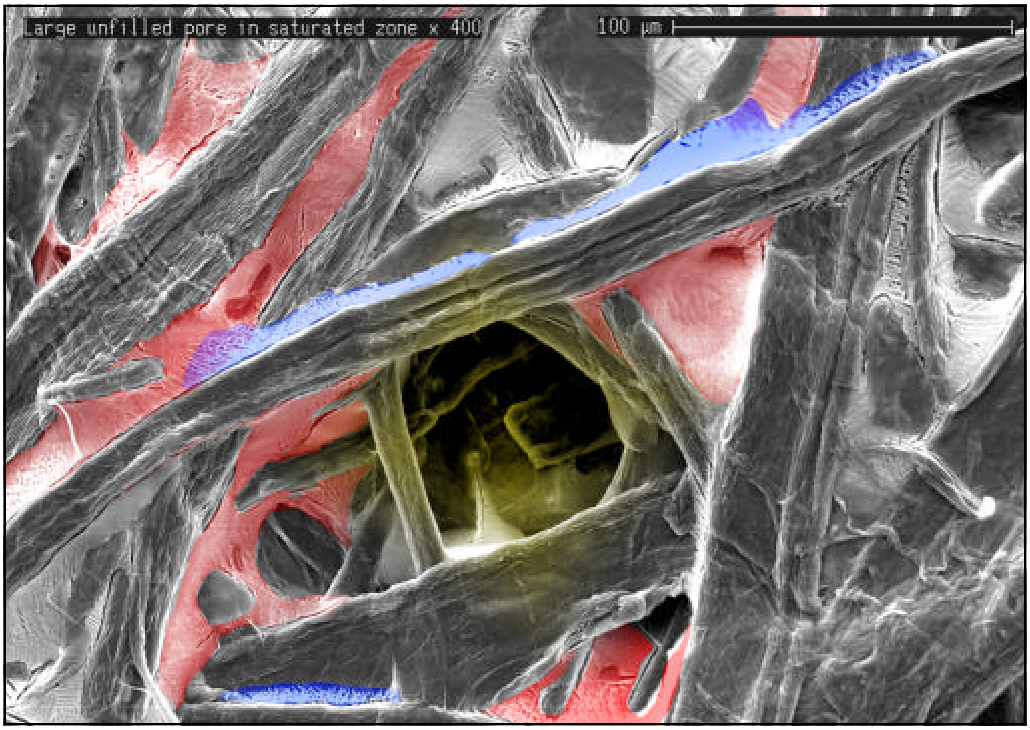
November 2003 — Making materials matter

Paper chase

Reworking basic theory on fluids and paper

On paper, Ray Roberts' forest industry career looked set in concrete. Then he was asked to learn a little materials science to solve a few problems with low pressure melamine coated fibre board and before he knew it Ray was back at uni as a student. The little questions quickly opened up some fundamental issues about the material properties of paper, and Ray's forestry career was shelved for the researcher's life.

Scanning electron microscope of fluid inside the partially saturated zone of paper. Pores are unfilled. New research is showing that fluids move through paper as film flow, not via the bulk filling of pores. ▶▶



lia. His boss encouraged him to develop the science to understand the problem, so Ray returned to the ANU as a part time Masters student in 1999 (under the guidance of Dr Phil Evans, CSEM's former director).

Melamine board is made by saturating panels of wood fibre with urea formaldehyde and then coating it with melamine resin. In many instances defects were appearing in these surface coatings reducing the value of the product.

"I'm not sure that anyone realised what I was getting in to when I began investigating problems with melamine panels," says Ray. "It was relatively easy to explain why the defects were happening but quite challenging to go the next step and develop a solution from first principles. What we quickly discovered was that our understanding of these systems was far from complete."

Problems with melamine

Ray originally graduated from ANU with a degree in Forestyry. He then spent 25 years carving out a highly successful career in the forestry industry working in both Tasmania and NSW as a forester and in production and technical management. While based at Tumut he became involved in addressing defect problems with low pressure melamine panels, one of the main products coming out of the mill and an important export growth area for Austra-

Paper and fluids

"The problem with melamine panels lies in both stages of its production. First, using a mix of scanning electron microscopy and RAMAN

(Continued on page 2)

Inside this MM

Volume IV, Issue 10

Materials Monthly is produced by the ANU Centre for Science & Engineering of Materials

Holes in the fabric

The Landauer formula without Landauer's assumptions

It's generally accepted that the physics and technology of electron transport in nanodevices are fully explained by the seminal work of the late Rolf Landauer, an eminent IBM scientist, who advocated that *'transmission is conductance'.* The Landauer formula, which he derived for non-interacting electrons in a one-dimensional uniform conductor, has wide applications for a variety of physical systems including quantum wires, quantum-Hall edge states, quantum point contacts, and carbon nanotubes. The formula has been commonly used in explaining mesoscopic conductance in many text books and hundreds of research papers.

However, the formula fails to explain several observed phenomena and a new analysis by Dr Mukunda Das, from the Department of Theoretical Physics (RSPhysSE, ANU), with colleague Dr Fred Green, from the University of NSW, is set to throw a cat amongst the theoreticians because it reveals a raft of problems in Landauer's model. Experimental evidence has shown that there is finite conductance in quantum nanodevices. This finite conductance is the result of energy being dissipated. Unfortunately the Landauer formula is unable to provide a microscopic analysis of the physics of dissipation. In his book *The physics of low dimensional semiconductors,* J. H. Davis writes about the Landauer formula "... energy must be supplied to support conduction, even through a perfect wire, but leaves open the question of how this energy is dissipated."

▲▲ Makunda Das: rocking the boat

Mukunda Das and Fred Green have now answered the question of how the dissipation occurs in a perfect wire by removing many of the assumptions that Landauer established in the process of deriving his formula. Their theory is based on quantum kinetic formalism, which respects all the basic principles of electronic transport. The analysis they carried out provides a solid foundation for quantum transport in mesoscopic devices. Now this long-awaited result will make a difference to our basic understanding of the subject, and you can read all about it in their paper titled the 'Landauer formula without Landauer's assumptions' which has just been published in the British Institute of Physics' Journal of Physics: Cond Matter 15, L687-693 (2003).

When asked if he expected the paper would provoke a response, Mukunda commented: "In that we've demonstrated a basic tenet of solid state physics is invalid, I expect we'll be receiving significant feedback. Most of it will be positive but there will probably be a few brick bats, too. You have to expect that when you rock the boat."

More information: Mukunda.Das@anu.edu.au

Paper chase

(Continued from page 1)

spectroscopy, I demonstrated that there's inadequate saturation in decor papers with urea formaldehyde resin leaving voids. Then, there's an excessive flow of melamine resin into these voids causing an inadequate surface coating.

"The underlying problem, therefore was one of fluid flow, and this literally opened up a Pandora's box of problems because it quickly became apparent that our models of how liquids flow through and over paper materials, and melamine panel is really just another form of paper, were inadequate and incomplete."

Once fluid flow was identified as the problem, the study became a generic one on fluid flow in paper, and Ray converted his masters to become a full-time PhD student in 2001 working out of the Department of Applied Maths (RSPhySE).

"This is a big field of enquiry with enormous potential," comments Ray. "Most problems with paper relate to the manner in which it interacts with liquids. In effect, paper is all about working with liquid be it to absorb liquid that's been spilt (mopping up), display liquid that's been coated on (ink) or protecting a product from liquid (packaging).

"Amazingly, with paper being such a universal material, we didn't have a basic understanding of how fluid moved through paper."

Penetrating paper

To gain a better understanding of fluid penetration into paper, you need to characterise the morphology of the pores in the fibre web and develop an understanding of the physical processes which affect fluid movement and fluid-solid interactions during fluid penetration.

The traditional approach had been to assume that the major mechanism for fluid penetration in to paper was via capillary transport within pores. The rate of penetration was believed to be a function of the balance between surface tension and viscous drag. The interfacial contact angle had been assumed to be constant and pore morphology was reduced to an equivalent cylindrical pore. Unfortunately, this idealised approach failed to explain much of the observed behaviour of fluid penetration into paper.

Working with Tim Senden and Mark Knackstedt from Applied Maths, Ray began experimenting with cryo-scanning electron microscopy to visualise the transport mechanism of a wetting fluid during fluid penetration. A variety of sample unsized papers were wetted, snap frozen at different instances over time and then examined by SEM for details on where the wetting front was at, and how the fluid was advancing.

"Our observations immediately found problems with the

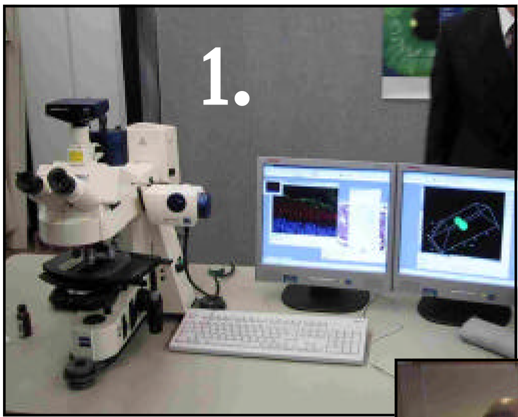
(Continued on page 5)

A tale of 3 micros

On the afternoon of Thursday, 23 October, the ANU Electron Microscope Unit celebrated the acquisition of two new machines and the management responsibility of an existing Leica spectral confocal light microscope from RSBS. The new microscopes are:

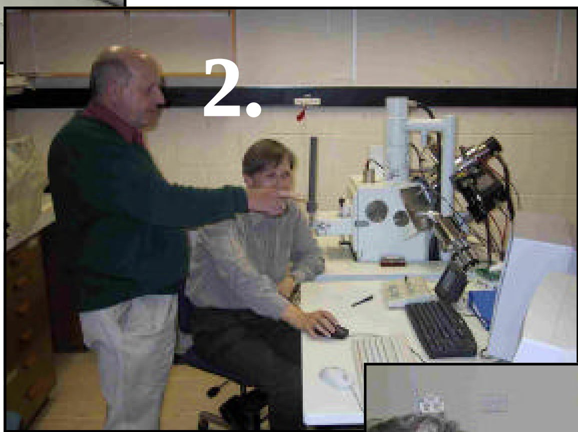
- a Focused Ion Beam coupled with a Scanning Electron Microscope (FIB/SEM); and
- a Zeiss ApoTome deconvolution light microscope

A large crowd gathered to hear Prof John Hearn (DVC for Research), Prof Malcom Gillies (DVC for Education), Prof Jonathan Stone (Director RSBS), and Dr Sally Stowe (Facility Coordinator, ANUEMU) 'bless' the three pieces of technology.



▲▲ the ApoTome deconvolution microscope

The speakers outlined the importance of the new microscopes to the research effort at ANU, and discussed the ongoing challenge of ensuring that ANU's researchers had access to leading-edge technology. Sally pointed out that FIB/SEMs have been available for nearly a decade but that this was how long it took to plan and mount a successful campaign to acquire such facilities. Consequently it's important to be monitoring new developments in microscopy and analysis, and to be planning well into the future.



▲▲ the FIB SEM in action.

Following the speeches, guests were encouraged to check out the three new machines for themselves.

The FIB /SEM has been described as a nanoscale Swiss Army knife for its versatility and flexibility (see the September issue of MM, p3) in cutting materials on a scale of nanometres. It was bought from ANU equipment funds and an ARC LEIF grant, with a contribution from UNSW.

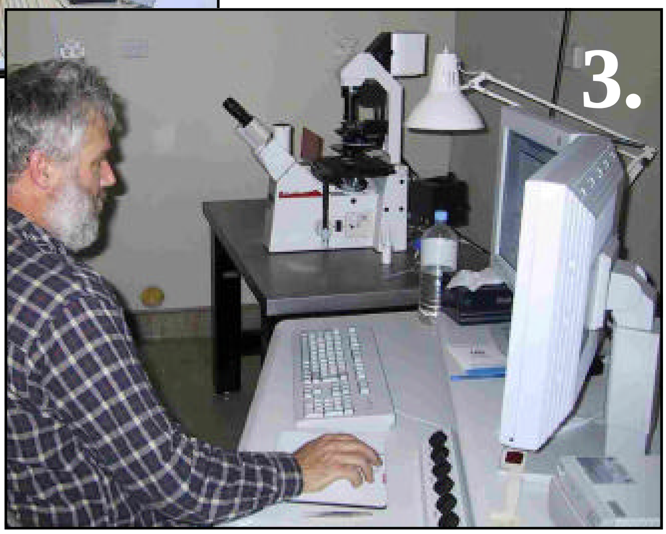
A standard deconvolution epi-fluorescence light microscope records images at a series of different depths through of a sample, and then digitally processes them to remove scattered and out-of-focus light. This process is very slow because of the amount of computation involved - it can take many hours to process a single sample. **The Zeiss Apotome** speeds the process up to close to real-time, by using the image of a moving grid projected onto the sample to detect in-focus features. The result is an immediately available 'optical section' of greatly improved resolution. A series of sharpened images can be reconstructed into a 3D image.

▲▲ Jonathan Stone 'blesses' the 3 microscopes.

The National Institute of Bioscience made the acquisition of the microscope possible with a contribution of $25,000, in addition to contributions from the ANUEMU and from researchers.

.The **spectral confocal microscope** also allows 3-D reconstruction of fluorescent specimens, for instance those labelled with fluorescent antibodies, and can examine the precise wavelength distribution of light emitted by a sample.

The launch of the three microscopes also signalled a shift in focus for the ANUEMU away from pure electron microscopy and x-ray microanalysis towards the broader range of microscopy, including light microscopy, crucial for modern research. Support for advanced light microscopy has also been greatly improved by the transfer to the ANUEMU of Daryl Webb.



▲▲ Daryl Webb on the spectral confocal microscope

More information: Sally Stowe (stowe@rsbs.anu.edu.au)

Opportunities

Last call for CSEM Prizes

Time is running out to enter this year's CSEM Prizes. **Entries close on 30 November** (which is a Sunday so we'll still accept entries on Monday, 1 December).

The CSEM Prizes aim to reward excellence in materials science and engineering at an undergraduate level by offering a $2,000 award for the best final year thesis. There are two prizes on offer. 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**'.

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.

Last year we 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.

So, if you know anyone worthy of being considered, please let them know as soon as possible. This year's event is rapidly drawing to a close.

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

More industry & innovation

In addition to the **Australian Materials Technology Network** (see the May MM) AusIndustry's Backing Australia's Ability scheme has also funded two other major industry/innovation programs. These are the InnovationXchange and the Industry Techlink.

▶ The **InnovationXchange** is a one stop exchange connecting industry to the world of innovation.
▶ **Industry Techlink** has a pool of skilled technology consultants to help industry resolve problems.

If you want to figure out what this means, check out their websites:

http://www.innovationxchange.com.au/

http://www.industrytechlink.com.au/

National Hydrogen Study

The report of the National Hydrogen Study, commissioned by the Commonwealth Department of Industry, Tourism and Resources, has concluded that the development of hydrogen as an energy resource is likely to offer Australia a large number of opportunities.

The report, prepared by ACIL Tasman and Parsons Brinckerhoff, recommended that a national vision be developed and that an Australian Hydrogen Group be formed, with funding support for a secretariat from the Federal Government, to assist driving the hydrogen agenda and the implementation of agreed recommendations. The report is available at **www.industry.gov.au** (look under What's New)

Diary: conferences and seminars

◀✧▶▶▶ **Modern Science of Advanced Materials** — **17-19 December**
Townsville, Qld, http://www.eng.jcu.edu.au/newevents/MSAM_2003.pdf

◀✧▶▶▶ **Photons@work** — **27 Jan—5 Feb 2004**
Australian Synchrotron Summer School, ANU, http://wwwrsphysse.anu.edu.au/sync.school/

◀✧▶▶▶ **ACMM-18** — **2-6 Feb 2004**
Aust Conference on Microscopy and Microanalysis 18
Geelong, http://www.deakin.edu.au/events/acmm18/

◀✧▶▶▶ **28th Annual Condensed Matter and Materials Meeting** — **3-6 Feb 2004**
Charles Sturt Uni, Wagga Wagga, http://www.tip.csiro.au/wagga/

◀✧▶▶▶ **Planetary timescales: from stardust to continents** — **16-19 Feb 2004**
Elizabeth and Fred White Conference
Australian Academy of Science, Shine Dome, http://www.mso.anu.edu.au/PSI/white_conference.html

◀✧▶▶▶ **7th World Biomaterials Congress** — **17-21 May 2004**
Sydney, http://www.tourhosts.com.au/biomaterials/

◀✧▶▶▶ **ICSM 2004** — **28 June—2 July 2004**
International Conference on the Science and Technology of Synthetic Metals,
Uni of Wollongong, http://icsm2004.uow.edu.au/

◀✧▶▶▶ **VUV 14** — **19-23 July 2004**
14th International Conference on Vacuum Ultraviolet Radiation Physics,
Cairns, Qld, http://vuv14.anu.edu.au/

◀✧▶▶▶ **SIF2004** — **26-29 September 2004**
International Conference on Structural Integrity and Fracture,
Brisbane, Qld, http://www.cat.csiro.au/SIF2004/

◀✧▶▶▶ **AMAS 7** — **18-20 February 2004**
The 7th Biennial Symposium of the Australian Microbeam Analysis Society,
Uni of Melbourne, http://www.microscopy.org.au/amas/AMASVII/Symposium_HomePage.html

Paper chase

(Continued from page 2)
traditional model," says Ray. "Instead of witnessing fluid flow as an advancing wetting front moving along the bulk of the pores, we observed a large and diffuse partially saturated zone where fluid occupies only the edges of pores and forms films along channels formed by fibre overlaps.

"This result indicates that the fluid movement is due primarily to the advance of the wetting fluid in the form of bulk liquid films along these channels, not as bulk filling of the pores."

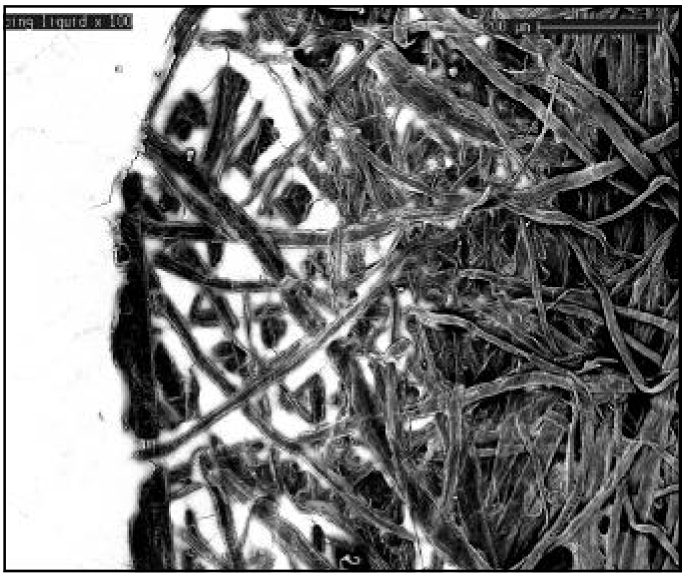
Flow with the film

To understand the observed flow behaviour, the researchers analysed the potential flow paths for the wetting fluid at different length scales. These include flow within the pores, along channels formed by fibre overlap, along the fibre indentations caused by fibre collapse during pressing, and intrafibre flow. Their analysis showed that continuous displacement of a meniscus along bulk pores is highly unlikely due to the presence of discontinuities in the pore morphology. The preferential displacement mechanism is actually via film flow.

"The channels formed by fibre overlaps are highly interconnected and form a dense network of flow paths which efficiently transport the wetting fluid," comments Ray. "The experimentally observed penetration rate is consistent with our theoretical calculations of film flow through channels."

Ray then demonstrated the process of fluid flow using two-photon laser confocal microscopy at BASF Ludwigshafen using a special cryogenic cell developed in the Dept. of Applied Maths and constructed in the workshop at RSPhysSE. This method enables one to obtain 3-D images of fluid penetration at arbitrary depths and below the droplet. Interfibre channel flow is observed under the films in the saturated zone near the droplet edge. Interfibre channel flow and unfilled void spaces are also observed directly underneath the droplet.

"This result confirms that the primary mechanism for fluid



▲▲ Liquid advancing through paper fibre .

▲▲ Ray Roberts .

penetration in unsized paper is via film flow along interfibre channels," says Ray. "It's a pretty basic discovery, and it tells us that the pore space of paper, together with local surface energy considerations, are the chief determinants of fluid penetration. Understanding these relationships and their implications for paper performance opens up vast opportunities for designing paper products with improved characteristics, and more adeptly troubleshooting problems, such as the original melamine problem, when they arise."

And now that he has his head into materials science, will Ray be returning to industry?

"Not for the foreseeable future," Ray comments. "The pay's not the same as in private industry but the stimulation and fulfillment of a the research career just can't be compared with. What's more, you're surrounded by the best people. This is a colossal department to work in."

And the feeling is probably mutual. For his pioneering efforts on paper and fluid flow, Ray was presented with the Directors Award for Best Student Paper* at the recent RSPhySE Founders Day.

*Spreading of aqueous liquids in unsized papers is by film flow, R Roberts, T Senden, M Knackstedt and M B Lyne (2003), Journal of Pulp and Paper Science: Vol. 29, No. 4 p123-131

More information: Ray.Roberts@anu.edu.au

Words of substance

"The only means of strengthening one's intellect is to make up one's mind about nothing - to let the mind be a thoroughfare for all thoughts. Not a select party."

John Keats

"Truth is stranger than fiction, but it is because fiction is obliged to stick to possibilities; truth isn't."

Mark Twain

the backpage

MM webspotting

Paper chase

- **Paper properties and degradation**
  http://www.si.edu/scmre/relact/propndeg.htm
- **Paper characteristics and their importance**
  www.upmpreprint.com/2A92E1423FA04AE2882AA02C3684008B.htm
- **Glossary of paper properties (Robert Paper Co.)**
  http://www.robertpaper.com/paper_properties.htm
- **The world of paper**
  http://www.biltpaper.com/p_properties.asp
- **Institute of paper science & technology**
  http://www.ipst.edu/research/paper_physics/end_use_refine_bond.htm
- **Superb paper planes**
  http://www.josephpalmer.com/planes/Airplane.shtml
- **Paper snowflakes**
  http://www.highhopes.com/snowflakes.html

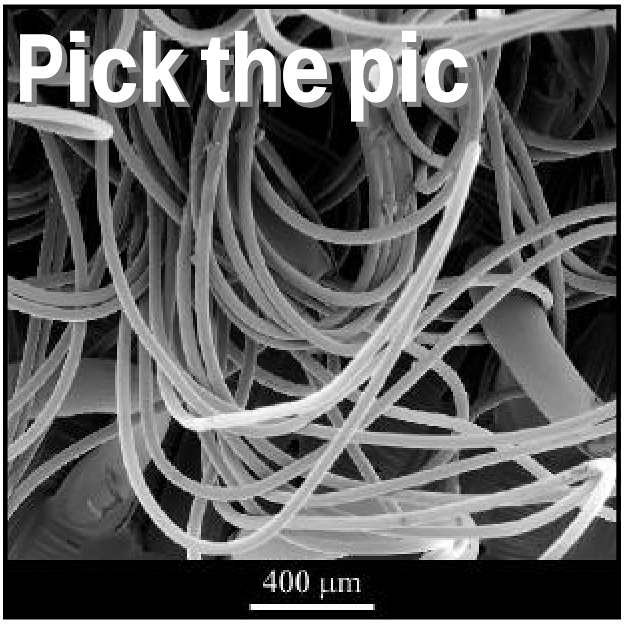
CSEM

ANU Centre for Science & Engineering of Materials

Institute of Advanced Studies
Research School of Biological Sciences
Research School of Chemistry
Research School of Earth Sciences
John Curtin School of Medical Research
Research School of Physical Sciences & Engineering

Faculties
Department of Chemistry (Faculty of Science)
Depart of Engineering (Faculty of Engineering and Information Technology)
Department of Geology (Faculty of Science)
Department of Physics (Faculty of Science)

National Institute of the Arts
Materials Workshops



Getting stuck on nylon

What happens when you place one surface covered in flexible nylon loops up against another surface covered in stiff polyester hooks? What happens is you get stuck fast. The system, of course, is Velcro and it was inspired by Nature. Seeds (burrs) covered in tiny hooks are great at hitching a ride in the socks of passing bush walkers (or in the fur of passing animals). The observation was the basis of Velcro which was invented in Switzerland in 1948 by George de Mestral.

It was taken by J Curran from the Department of Materials Science and Metallurgy, University of Cambridge.

[The above image, and many more stunning images of a variety of materials, can be found in the DoITPoMS Micrograph Library run by the University of Cambridge.]

See http://www.msm.cam.ac.uk/doitpoms/miclib/index.php

Check out the Commonwealth Govt's science portal for an overview of programs and funding sources ▼▼

Contacting CSEM

Director: **Dr Zbigniew Stachurski / Ph: (02 6125 5681 / Email: zbigniew.stachurski@anu.edu.au**

Communications: David Salt / Phone: (02) 6125 3525 / Email: david.salt@anu.edu.au

Administration: **Sylvana Ransley / Ph: (02) 6125 3525 / Email: sylvana.ransley@anu.edu.au**

Fax: (02) 6125 0506, Postal: Department of Engineering (Bld #32), Australian National University ACT 0200
Location: Room E212, Department of Engineering (Bld #32), cnr of North Road and University Ave, ANU

Materials Monthly **comes out each month. We welcome your feedback and contributions. Please send them to David Salt, Editor, *Materials Monthly,* care of CSEM.**
Please let us know if you wish to be added to our electronic or postal mailing lists.
Electronic copies of *Materials Monthly*, useful links and additional information about CSEM can be found at our website.

www.anu.edu.au/CSEM