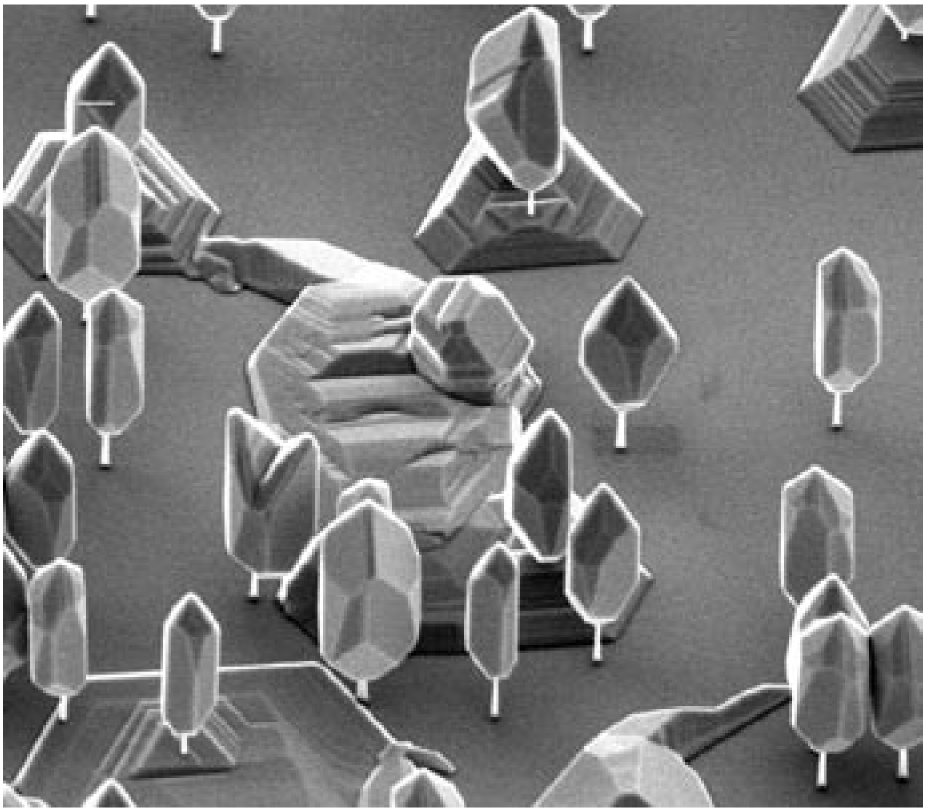
CSEM's
Materials Monthly
November 2006 Making materials matter

Lollipops in nanospace

Weird scenes inside the goldmine

The alien scene pictured on the right depicts crystals of pure gallium antimonide sitting on top of spindly stalks of gallium arsenide. The stalks are around 30 nm in diameter. The formations were grown by Dr Michael Gao, a postdoctoral fellow in the Department of Electronic Materials Engineering (RSPSE), and represent new efforts to work with the semiconductor gallium antimonide.

"There's a lot of interest in working with gallium antimonide," says Dr Gao. "It possesses a band gap the makes it an excellent material for many optoelectronic devices such as lasers and infrared detectors and LEDs. Unfortunately it's very expensive and it's difficult to deposit on other more commonly used semiconductor wafers like gallium arsenide.



"That's because gallium antimonide has a larger lattice constant than gallium arsenide. When it crystallises on top of a wafer of gallium arsenide, large amounts of tension develop in the crystal structure of the gallium antimonide as the two crystal structures attempt to match. This tension prevents the gallium antimonide from forming smooth layers or growing into usable shapes.

"However, we have discovered that if you grow gallium antimonide on top of a nanowire of gallium arsenide that the gallium antimonide crystal can grow without large amounts of tension. We believe this is because the nanowirebase from which the gallium antimonide is growing is small enough not to impose its crystal structure on the newly forming crystal."

Dr Gao's work is part of the research of Professor Chennupati Jagadish's Semiconductor Optoelectronics and Nanotechnology Group on nanowires (see the March 2006 issue of *Materials Monthly*). The Group has been growing nanowires by placing nanoparticles of gold onto semiconductor wafers of gallium arsenide. The sample is then placed in their MOCVD (Metal Organic Chemical Vapour Deposition) chamber and heated causing the gold nanoparticles to melt. Gallium and arsenic atoms are then passed over the sample in the form of a vapour and a nanowire of pure gallium arsenide starts to grow under the gold droplet.

Dr Michael Gao with fragments of gallium arsenide wafers he's used as a base for growing forests of nano - lollipops.

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Lollipops in nanospace

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“While there is some controversy as to the exact process involved, most researchers believe that what we’re witnessing is a vapour-liquid-solid growth pattern,” explains Professor Jagadish. “Gallium arsenide in the vapour diffuses into the liquid gold/gallium droplet.

“The droplet quickly becomes supersaturated with gallium and arsenic atoms which crystallise into a gallium arsenide solid underneath the droplet. More vapourised gallium and arsenic diffuses into the molten drop and more gallium arsenide then crystallises underneath causing the column to grow – and grow.

“From our trials we’ve learnt that the critical variables involved in growing nanowires under gold nanoparticles is the size of the particles, the density and distribution of the particles on the wafer, and the heat at which the nanowires form.”

Having become confident in their capacity to grow simple gallium arsenide nanowires the researchers are now exploring a variety of ways of modifying the wires, including the incorporation of different elements.

“By using different reactive species in the vapour such as indium, gallium and arsenic you can incorporate different compounds into the nanowire thereby giving it different electro optical properties”, says Professor Jagadish. In this manner we’ve been able to grow indium arsenide and gallium arsenide hetero-nanowires.

“We’ve shown that when gallium arsenide starts growing on top of an indium arsenide base stem that the nanowire has a greater taper due to the fact that the gallium arsenide has a smaller lattice constant than indium arsenide.”

In a similar manner, but in reverse order, the hetero-nanowires that Dr Gao is growing has gallium antimonide on top of gallium arsenide. Because the gallium antimonide has the larger lattice constant it grows out rather than tapering in. In so doing it forms nanoscale lollipops, popsicles or match heads depending on the particular growth treatment being trialled. As with the simpler nanowires, it seems the size of the gold nanoparticles, their density on the wafer and the heat experienced during growth are key determinants of what shape forms.

So, all these amazing forms are variants of gallium antimonide/gallium arsenide hetero-nanowires. However, we think ‘lollipops in nanospace’ is just as fitting a descriptor.

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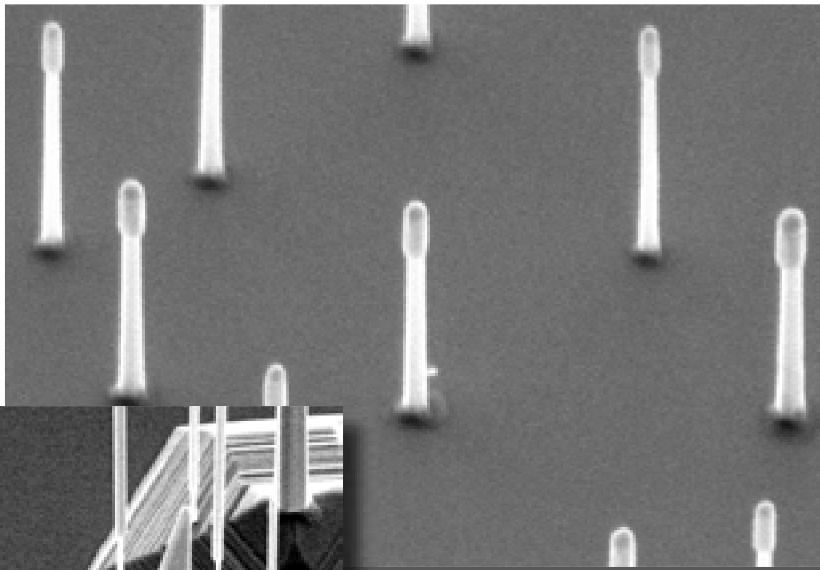
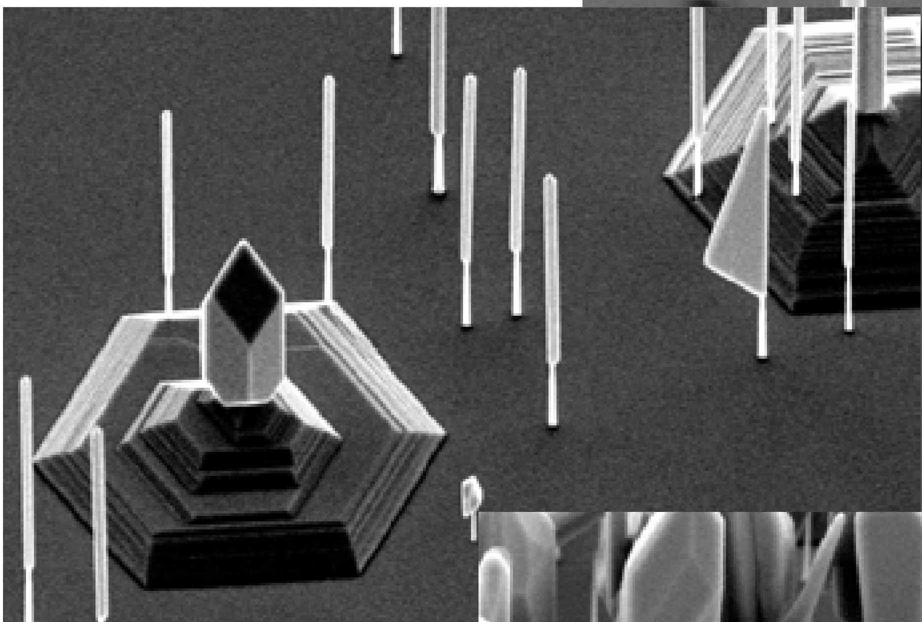
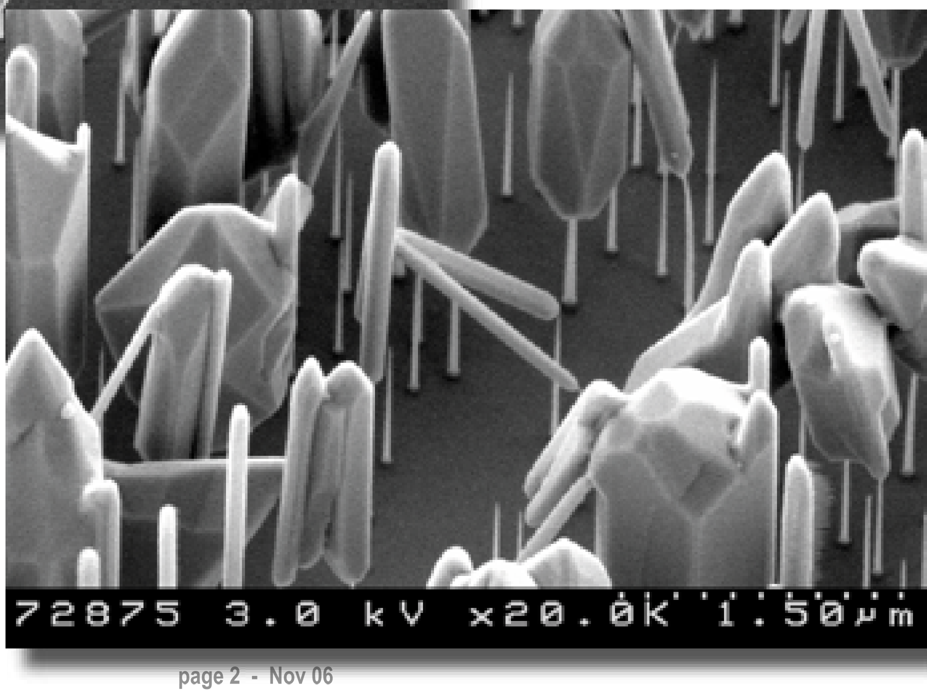


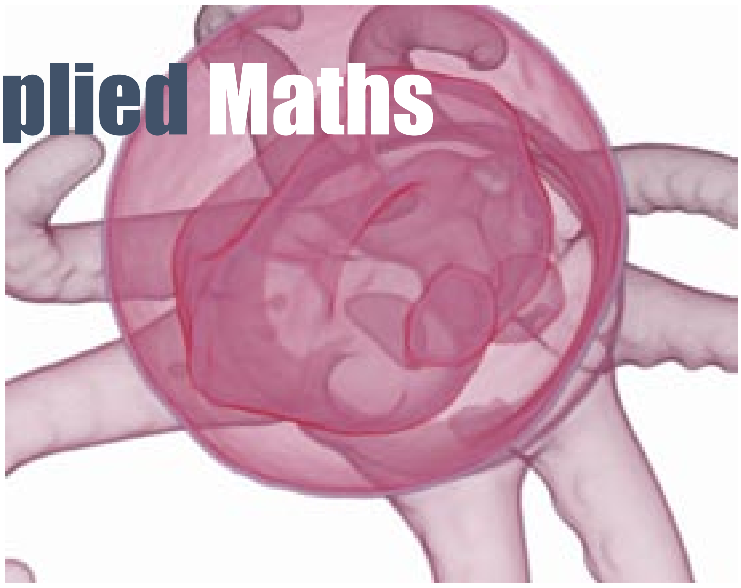


Some variants of the hetero-nanowires. Above are nano match heads. To the left are a variety of forms including a nano flag and nano batons, and a structure that might be suitable as a nano altar. Below is a nano forest formed from a high starting density of gold nano particles. All of these images were taken with a scanning electron microscope at the EMU. Dr Gao commented that when nano lollipops were too close together that they would bend and touch during the SEM session. This is evident in this lower image.



Mixing art with Applied Maths

A fascination with little plastic toys, X-rays and different ways of seeing the world has resulted in the creation of a range of new art based on the output of the CT facility at Applied Maths. For the past three months Ms Erica Seccombe has been an artist-in-residence in the Department of Applied Mathematics (Research School of Physical Sciences and Engineering) courtesy of funding from artsACT. Here she discusses the opportunity.



A frame from the animation Ocular *created by Erica Seccombe during her stay at Applied Maths as an artist-in-residence. It was created by CT scanning the plastic octopus (pictured on the screen in the image, lower left corner of page).*

I've long held an interest in X-ray imaging and scientific processes. Prior to my time at Applied Maths I was studying in the Department of Printmedia at the ANU School of Art. While there I experimented with a collection of miniature plastic animals and this gave me an idea on what I might do while at Applied Maths.

The plastic creatures, no bigger than 3cm long, are representations of native Australian animals. They come inside *Yowie* chocolate eggs.

My working methodology at the School of Art in creating images mimicked that of a scientific investigation. I categorised and selectively flatbed scanned each creature before subjecting its data to a series of rigorous visual manipulations within the controlled environment of *Photoshop*. This treatment rendered the creatures transparent, as if splayed on the glass slide and viewed down the lens of a microscope. With this perspective I began to investigate the concept of scale and the role of the observer.

I found the species of miniature plastic animals which proved to be the most successful subjects of my investigations were insects and sea animals. Their moulded shapes are so well produced that they do not immediately appear as replicas when enlarged. One of the works of art from my graduation series is a six metre inkjet print of a centipede.

During my residency at Applied Maths I was given the opportunity by Dr Tim Senden to X-ray these same plastic animals using their X-ray Computed Tomography facility. In the process I had to learn how to animate the resulting data using the volume-rendering program *Drishti*. *Drishti* is a software program created by Dr Ajay Limaye from VisLab (part of VisLab at the ANU Super-computer Centre).

In a few weeks I was able to make a simple rotation of a plastic octopus. I felt that I knew this object well and could imagine what the structure inside would look like as I have put it together many times. However, I was still surprised at how beautiful it looks when imaged using X-rays.

Using *Drishti* I made a two minute animation of the object being rotated and then had the camera eye travel through its transparent body before it is broken up and abstracted with only the end of its tentacles spinning in space before dissolving. I've entitled the animation *Ocular*.

I have already had the opportunity to exhibit this new work. During my residency I travelled to the UK for two weeks in September with my artist colleague Alison Munro to set up our exhibition called *Super Natural* at the Manchester University's Alsager Art Centre. Both our work for this exhibition makes use of print technologies as an analogy for contemporary scientific techniques and processes such as nanotechnology and genetic profiling to examine issues of vision, visualisation and replication of the natural world.

These technologies provide an increasingly minute view of nature. Rather than necessarily providing a clearer or more accurate view, they merely provide a different one. The works also examine the role of popular science in mediating and constructing our understanding of the natural world and the other non-science disciplines.

I projected the animated *Ocular* on a far wall with the six metre centipede print stretched out on the floor in front. It was the perfect opportunity to exhibit this animation of the octopus and I felt encouraged by the positive reception it received.

Everybody in the Department of Applied Maths and at the School have been incredibly generous with their time and I appreciated their efforts to explain their research to me – even when it went over my head. I've had a great time.

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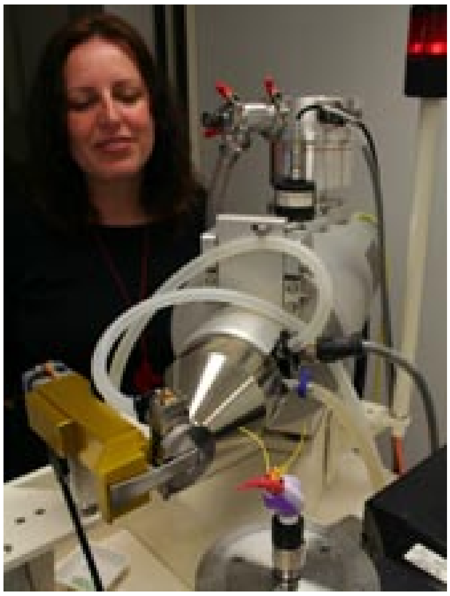


Erica Seccombe in the CT room at Applied Maths with one of the plastic creatures.

Crushing timber releases engineers

How many careers in engineering have begun with the destruction of a small model bridge? It's impossible to say but there's no denying that the annual bridge design challenge is always a winner with engineering students taking the course ENGN1221 - STATICS

But the contest is possibly a bit more sophisticated than it first appears because it's not simply about building the strongest bridge with limited materials but coming up with a design that will function in a predictable manner.

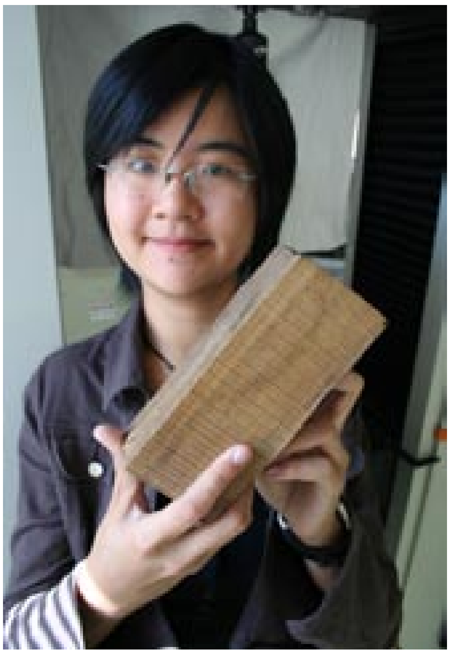
Students are given four lengths of balsa wood and are required to cut and glue these lengths to create a bridge span that will undergo destructive loading in the Instron. Points are awarded for the bridge that can carry the biggest load but more points go to the team that can predict when their bridge will fail.

The bridges weigh between 8-10 grams and support an average load of between 200-1000 Newtons.

So engaged were the students by the challenge that after the testing, and the formal marking part of the exercise, several groups came forward and asked for a second chance to rebuild and improve their design – just to prove to themselves they could do it.

Squeezing wood releases electricity

Over the summer break Ms Li Kim Tan will be squeezing wood to investigate its piezoelectric properties. Ms Tan is in the third year of a joint Bachelor of Engineering and Commerce. She has been awarded a Summer Scholarship by the Department of Engineering to study a puzzling materials phenomenon that has been known for over 50 years but is little understood. That phenomenon is the generation of electricity by squeezing wood.



Ms Li Kim Tan is investigating the piezoelectric properties of wood.

It's a form of the piezoelectric effect which is well understood in simple crystals but not much is known about it in more complex materials. In some crystals, known as piezoelectric crystals, it's possible to generate an electrical voltage by applying a mechanical stress to the crystal. The word piezo is derived from the Greek piezein, which means to squeeze or press. What makes the effect so valuable in many applications is that it's reversible. In other words, if you apply a voltage to a piezoelectric crystal it can will change its shape by a small amount.

"Li Kim Tan's study will establish a knowledge base and expand our understanding about piezoelectricity in plants and wood," says Dr Zbigniew Stachurski, Ms Tan's supervisor for the project. "We hope that through experiments and observation we might be able to model the piezoelectric phenomenon in cellulose fibre and characterise the piezoelectric properties of wood."

The research will be carried out in the Department of Engineering. Ms Tan will also be working with Dr Lui Yun from the Research School of Chemistry with inputs from Dr Colleen MacMillan at Ensis (a CSIRO collaboration in forestry research).

"The work is of considerable interest because many of the best peizoelectric materials such as PZT are lead based," comments Ms Tan. "In light of EU legislation against leaded materials the search is on for possible replacements."

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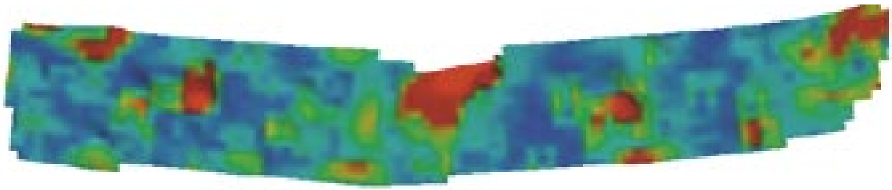
Making aluminium foam sandwiches

Aluminium foam is exactly what its name suggests – a foam made from an aluminium alloy. Sheets of the material come in a range of thicknesses with a variety of cavity sizes (the size of the bubbles in the foam) depending on how it's formed. What distinguishes aluminium foam is its high strength to low weight. Indeed, when you hold a sheet of aluminium foam it feels more like plastic than metal because it's so light.

It's a fairly expensive material but its special suite of properties means there's a growing interest in its application. Besides being stiff and light, aluminium foam is a good sound dampener, an excellent electromagnetic shield, provides good thermal insulation and it's great for high impact energy absorption (among other things, think bomb shielding here).



A strain distribution image produced by the Aramis system showing strain concentrations in the central deformation region as well as throughout the sample reflecting the cellular foam structure.

"The stiffness of the aluminium foam can be dramatically improved by combining it with a polymer facing on each surface of the foam sheet," says Ms Milli Styles, a PhD student in the Department of Engineering who is investigating possible uses of the foam. "In this way you are turning it into a sandwich composite. And making these composites is easy - just heat press a thermoplastic polymer on to each side."

Ms Styles is testing how aluminium foam might perform as a substitute for polymer foam in polymer sandwich composites (ie, polymer foam between two sheets of polymer).

"Aluminium foam is more expensive than polymer foam but its properties give it many advantages," she explains. "For starters, it's able to withstand higher processing temperatures allowing it to be used with thermoplastic skins meaning it can be recycled. The more traditional polymer sandwich composites use thermoset plastics so they can't be recycled."

In an effort to characterise aluminium sandwich composites and compare them with polymer sandwich composites Ms Styles has been carrying out a range of investigations into the flexural and impact behaviour of the two sandwich composites. This involved applying a series of load tests on the two composites using the Instron and measuring the resulting deformation using two cameras to record the process stereographically. She also carried out a series of impact tests.

She found that the metal foam structures possessed a different deformation mechanism and strain distribution to the traditional thermoset/polymer foam structures. The energy absorbed by the metal foam structure was found to be greater and it deformed gradually whereas the polymer structure displayed a more catastrophic failure. These features make the metal foam structure a better material for impact resistance.

Ms Styles is attempting to model the behaviour of aluminium composites to further explore their possible applications. "It's an extremely strong and light weight, impact-resistant material that's non combustible and recyclable making it a good choice when impact-resistant, structural materials are required."

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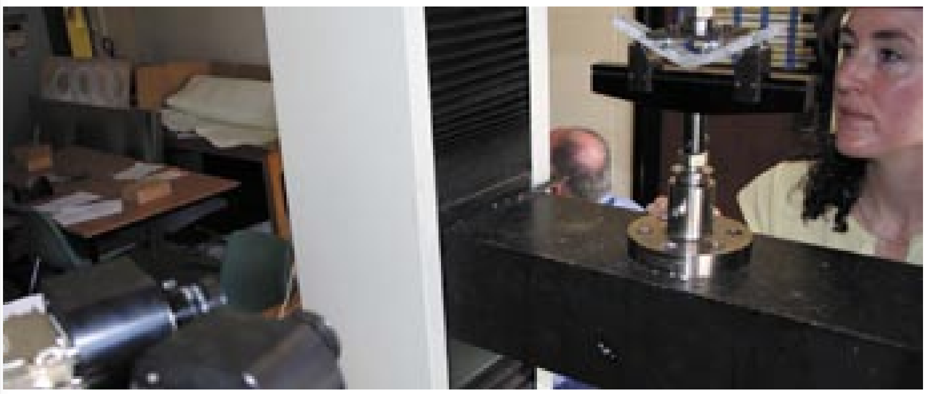
Milli Styles holds up three aluminium foam samples. The lower sample is a raw sheet of aluminium foam, the middle sample shows it with a coating of thermoplastic skin and the top sample is a section of the sandwich composite deformed from strength testing.

Making aluminium foam

One common method for making aluminium foam involves injecting gas into the aluminium melt using specially designed rotating impellers or vibrating nozzles. These generate fine gas bubbles which float up to the surface. Ceramic particles in the melt make the foam fairly stable allowing it to be pulled off the liquid surface with a conveyor belt. It's then allowed to cool and solidify. In the resulting solid foam the average cell size is inversely related both to the average cell wall thickness and to the bubble density. This can be controlled by adjusting the gas flow, the impeller speed or nozzle vibration frequency. Average pore size ranges from 25mm down to 3mm.



To analyse deformation in the aluminium foam composites Ms Styles used the ARAMIS strain analysis system. She first applied an increasing load onto the sample using the Instron. As it deformed, twin cameras (left-hand side of image) monitored its changing shape capturing stereo images of the deformation. Photogrammetric principles then track small correlation areas in successive images. ANU is the first Australian university to use the ARAMIS system.

The wiggler

Relativistic charged particles emit synchrotron radiation when forced to travel along a curved path by the application of powerful magnetic fields. Early synchrotrons used bending magnets to produce such radiation by confining orbiting electrons to a circular arc. Modern synchrotrons feature straight sections between circular arc segments where insertion devices can produce synchrotron radiation much more efficiently. One form of insertion device is the wiggler shown (to the right) undergoing final testing at the Advanced Design Consulting facility in Ithica, USA.

From December this state-of-the-art 2 m array of powerful permanent magnets will light up the x-ray absorption spectroscopy beamline at the Australian Synchrotron. With the gap between the pole pieces reduced to ~14 mm during operation, electrons traversing the evacuated straight section will wiggle (execute oscillations) in the horizontal plane, emitting highly collimated synchrotron radiation with each oscillation.

Relative to a bending magnet, the photon output will be increased by a factor of 2N where N is the number of periods (20 in this case) and the photon energies will be higher due to the increased magnet field (~1.9 T in the wiggler compared to ~1.3 T in the bending magnets). The result is 8.5 kW of output power and an enormous design challenge to direct photons of energies 4-45 keV from the wiggler onto the sample without melting either the beamline optics, the specimen under examination or the operator.

Dr Mark Ridgway, from the ANU Department of Electronic Materials Engineering, chairs the Beamline Advisory Panel for the X-ray absorption spectrosopy beamline. In conjunction with Australian Synchrotron personnel, the panel has been responsible for the specification and preliminary design of the wiggler and beamline. This is the first of several wigglers planned for the new national facility scheduled to open in 2007.

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$2000

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More info:
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