CSEM's

Materials Monthly

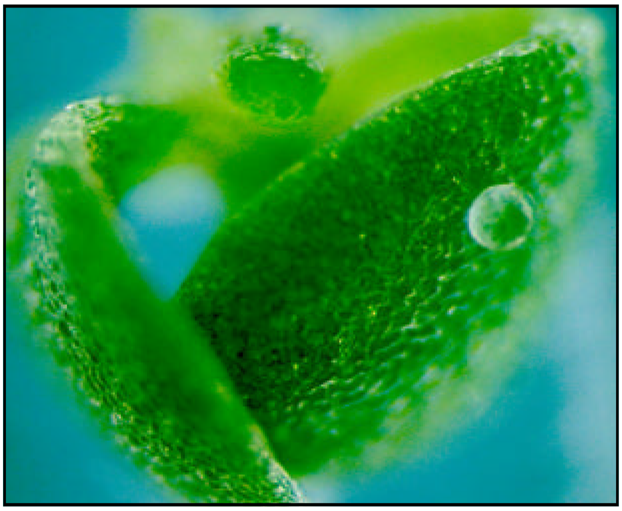
June 2004

Making materials matter

Deconstructing cell walls

Madeleine Rashbrooke's attempt to understand the role of a particular protein in controlling the deposition of cell walls in plants had a surprising outcome – the production of giant bubble-like cells in which growth was unconstrained. It wasn't an effect she was intending to create but it did confirm just how important a single protein could be in shaping plant cells.

It looks like a drop of water on the side of a plant leaf but it's actually a giant cell produced when the plant cell grows without constraint. A single gene controls many aspects of the shape a cell will become. ▼▼



Paper, timber and cotton are basically processed plant cell walls. The better our understanding of how these cell walls are shaped and formed, the greater the potential for us to modify their growth to produce a wide range of biomaterials (such as paper, timber and cotton) with enhanced properties.

Building cell walls

Cell walls fill the role of the vertebrate skeleton or insect exo-skeleton in giving the plant structural rigidity. Cell walls are made up of carbohydrate polymers (called cellulose microfibrils) in a meshwork of proteins and pectins. The cellulose fibres are deposited in loops.around the outside of the cell, like the steel hoops around a wooden barrel. They act to constrain cell expansion to the desired axis. Cells in a plant stem, for example, expand to form long cylinders rather than growing in all directions equally. The manner in which cells grow gives different parts of plants their characteristic shape (eg, stems are long and thin, leaves are flat and open). While animal cells also come in a range of shapes and sizes, growth is generally achieved by an increased number of cells as much as by making the cells bigger or a different shape.

What determines the arrangement of cellulose fibre outside the cell membrane? The textbook paradigm is that the deposition of these cellulose fibres is controlled by a 'cytoskeleton' of protein polymers that form matching loops inside the cell membrane. These are called microtubules as they look like tiny tubes in electron micrographs.

Microtubules are not unique to plants. They also occur in animal cells where they serve a function in pulling apart the pairs of chromosomes when cells divide. However, the loop arrangement is unique to plants – plants seem to have found new uses for a common fibre.

Organising microtubules

To understand more about how microtubules control cell expansion, Dr Geoff Wasteneys (formerly the head of the Cytoskeleton Laboratory, part of the at the Plant Cell Biology Group, RSBS; recently moved to Canada) created random genetic changes in *Arabidopsis*, a small fast growing plant that is used as a guinea pig in many plant studies. He then looked for plants that had abnormal microtubules. When these were identified he then isolated what the genetic change was that caused these abnormalities. In this manner he identified a gene that appeared to play a key role in the manner in which microtubules functioned. The gene was dubbed MOR1 (for microtubule organisation).

(Continued on page 2)

Madeleine Rashbrooke

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THE AUSTRALIAN NATIONAL UNIVERSITY

Deconstructing cell walls

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It turned out to be the plant version of a gene found in animals that coded for a type of protein that stopped microtubules from depolymerising. This was a surprise as it was thought the gene would be unique to plants as defects in this gene seemed to only affect the plant-specific microtubule loop arrangement.

The change that Geoff had induced was quite subtle. The mutated protein works fine at normal temperature but if the temperature increases more than a few degrees it stops functioning properly, however, it's still not known exactly how much function remains. The result is that cells tend to be less well shaped than normal plants. For example, in plants with the mutated gene, growth is normal at 21 degrees C but cells start to lose their shape definition if grown at 31 degrees C (for example, see images of leaf hairs).

So how does the MOR1 protein influence the arrangement of microtubules in plant cells? This was the research question that doctoral student Madeleine Rashbrooke has been attempting to answer. To resolve it she attached a visible tag to parts of the MOR1 protein. This tag is like a dye that is incorporated into the protein of interest, and allows that protein to be seen using a special microscope.

Marking MOR1

The tag the Madeleine used is the green fluorescent protein (or GFP) that naturally occurs in some forms of jellyfish. Using genetic engineering, Madeleine stitched the jellyfish gene into parts of the MOR1 gene. These spliced genes are used by the plant cells to produce pieces of MOR1 protein that fluoresce when placed in blue light. What Madeleine wanted to establish was: which individual parts of the MOR1 protein actually bind microtubules?

Well, that was what was supposed to happen but genetic engineering is a fickle craft that often doesn't go to plan. In this case, she was successful in stitching in the gene for the fluorescent tag to the MOR1 gene being studied, but then the gene was rendered inactive in a process known as 'gene silencing'. This sometimes occurs when the plant 'realises' that it's making proteins that are unnatural (as sometimes occurs when cells are infected by viruses). The cell's response is to stop making the problem gene – in this case the GFP-tagged bits of MOR1. In Madeleine's experiment it also shut down the production of the natural version of MOR1 protein.

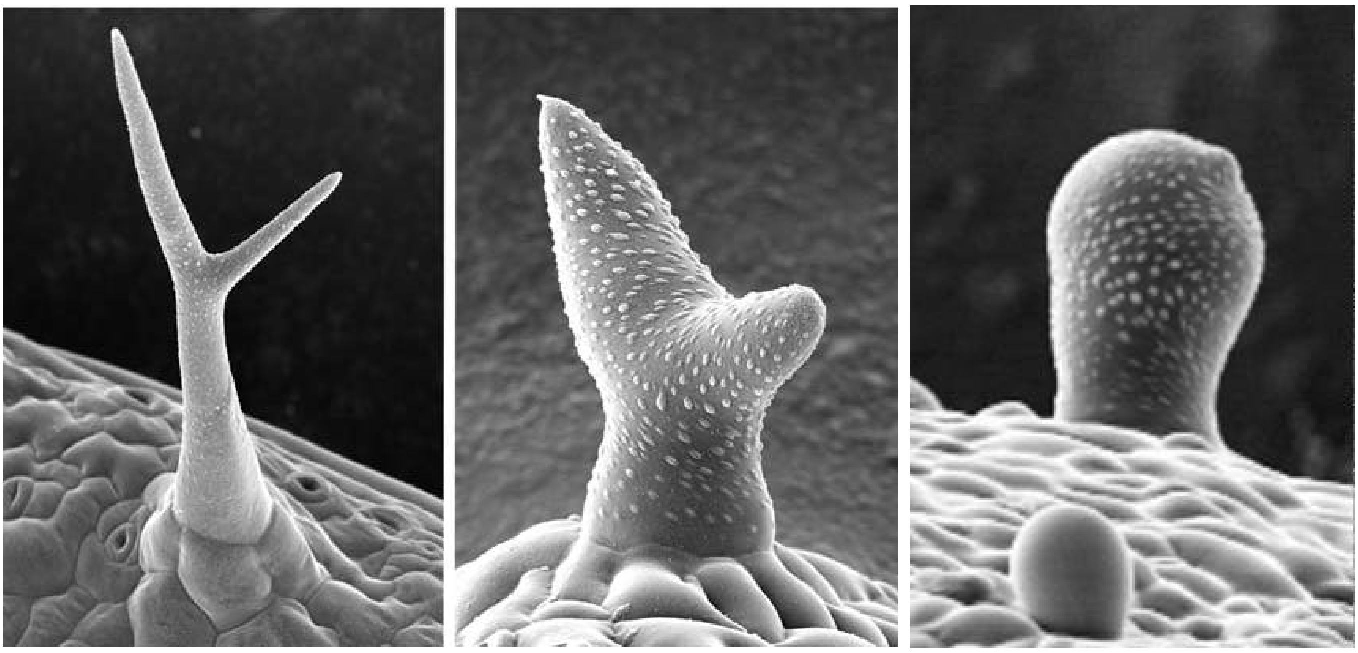
She set out to unravel how the MOR1 protein controlled the microtubules but instead produced some cells that have virtually no MOR1 at all. Because MOR1 is a protein that stops microtubules from depolymerising, an absence of MOR1 leads to the cell's microtubules breaking down.

Without microtubules inside the cell to control the process, the cell wall is not formed correctly. The direction and amount of cell expansion is uncontrolled, and some cells just balloon out The photograph above shows one such giant cell, which is hundreds of times bigger than a normal cell, and has a paper thin wall. It looks spectacular but collapsed a moment after the picture was taken. The effect of this near absence of MOR1 results in seedlings that are much worse than the original 'temperature sensitive' mutant plants.

Which just goes to show that even small manipulations to the cells genetic instructions can result in big differences to its shape and rigidity.

"By studying what happens when things go really wrong, we're given powerful insights on the factors that regulate cell shape and growth potential," says Madeleine. "Small manipulations of cell wall and shape properties could conceivably make a big difference to the quality of wood and cotton products. We're working to understand the control mechanisms within plant cells. The research is done at the fine scale but the broader applications could literally reshape the world of biomaterials."

More information: Madeleine.Rashbrooke@anu.edu.au



▲▲ Researchers at RSBS have been studying the effects of disabling the MOR1 gene. They have produced mutant plants in which a change in temperature affects how well the gene product works, and also genetically engineered plants so that the MOR1 gene is inactivated. The picture on the left shows a normal-looking leaf hair on a mutant plant at 21 degrees C. When the plant is grown at 31 degrees C, the partial loss of MOR1 gene function leads to leaf hairs being less well formed, as seen in the middle picture. The picture on the right shows an even more misshapen leaf hair on a plant whose MOR1 gene has been silenced.

Making materials sing

Materials for musical instruments

by Professor Neville Fletcher

Why are bells made of bronze, organ pipes of tin, flutes of silver, trumpets of brass, and clarinets and violins of wood? Is it just tradition, or is there some physical basis that makes these the best choices? Since the answer is different in different cases, let's consider them one at a time.

Ring that bell

A bell must be large and heavy if it is to sound a deep note loudly and the sound is not to die away too quickly. The material from which it is made and its shape will determine the sound. Metal is then the obvious choice, but it has to be a metal that can be melted and cast in a clay mould. The finished product must be hard, and internal vibrational losses must be small.

The choices 1000 years ago were bronze (a copper-tin alloy) or pewter (a tin-lead alloy). Everything else, including iron, was too expensive, and the melting point of iron was too high anyway. But pewter is too soft to withstand the blows of a heavy striker, so bronze (about 80/20 copper/tin) it must be. And it turns out to be a good choice, for the melting point is moderate (about 900°C), the material is very hard and durable, and internal losses are small. Even today when steel bells can be made and are less expensive, bronze turns out to perform better. Aluminium is fine for large handbells, since it's not too heavy, but has a poor performance in large bells because of its low density.

▲▲ Neville Fletcher is a visiting fellow in the Research School of Physical Sciences and Engineering after 20 years as Professor of Physics at the University of New England and 5 years as Director of the CSIRO Institute of Physical Sciences. He plays flute, bassoon and organ. His book with Thomas Rossing *The Physics of Musical Instruments* (Springer, New York, second edition 1998) gives more information on all the matters discussed in this article. Neville recently assisted in the design of a new gong for University House to commemorate its 50th anniversary. (see page 5 for more details)

Blow that trumpet

Wind instruments such as organ pipes, flutes and clarinets are quite a different matter, because the sound is produced by the vibrating air column and all the walls have to do is to confine it. Of course, if the walls are too thin or their material too flexible the air pressure may cause them to vibrate, particularly if the pipe section is square rather than circular, but in a round pipe the sound radiated from vibrating walls is only about 1/10,000 (–40 dB) of that radiated from the open end.

However, the choice of wall material does make a difference because it affects the geometry of the pipe mouth. Since wooden pipes are square in section, the wood must be several centimetres thick to make it stiff enough, while round metal pipes have a wall thickness of only about 1mm, and the geometrical differences at the pipe mouth make metal pipes sound 'brighter' than wooden ones. This time, the metal alloy of choice is essentially the tin-lead alloy pewter, with about 70% tin. The eutectic melting point at 61.9% tin is very low (183°C) and the necessary thin metal sheets can be cast by using a simple moving box arrangement to spread a liquid metal layer onto a cloth-covered stone table where it will solidify. The softness of the alloy doesn't matter in this case, since the organ pipes are carefully mounted in the case well away from impact, and it is an advantage for final voicing adjustments.

Hand-held wind instruments are a different matter as they have to be robust. Well seasoned wood was the material of choice, since it was relatively easy to bore out both the central channel and the finger holes. The best wood was rainforest hardwood with high density and fine grain, since it could be polished to a smooth finish inside the bore.

The flute, however, evolved to a new design with different keywork in the middle of the nineteenth century under the hands of the German silversmith/flute player Theobald Boehm. One of his major contributions was development of a coupled key system for playing modern chromatic music, but he also redesigned the bore shape from tapering to cylindrical with a carefully shaped head, used large pad-covered finger-holes, and made the instrument from thin-walled silver-alloy (90 to 93% fine) tube. These instruments were louder and brighter than classical wooden flutes because of these geometrical changes. Later makers have actually used gold alloy (11 to 16 carat) in their top models, since it is superbly easy to work with and does not tarnish. Since the top flute-maker in the company makes the gold flutes, their quality is always high, and only top players can afford them, but the sound has nothing to do with the metal. Despite this, flutes are sometimes even made from platinum (guess the price!), and there has been a special piece of music written for them titled "Density 21.5".

When it comes to trumpets and trombones, brass is

(Continued on page 5)

Top honour to leading materials scientists

June 2004 saw the announcement of prestigious Federation Fellowships being awarded to Professor Stephen Hyde and Professor Jagadish, both from the Research School of Physical Sciences and Engineering.

For a discussion on aspects of their research, see articles in earlier issues of *Materials Monthly* (March 2003 for Professor Hyde and September 2002 for Professor Jagadish; go to http://www.anu.edu.au/CSEM/newsletter.htm).

Here are excerpts from the official ANU press releases in response to the awards.

Congratulations to both Professors from CSEM.

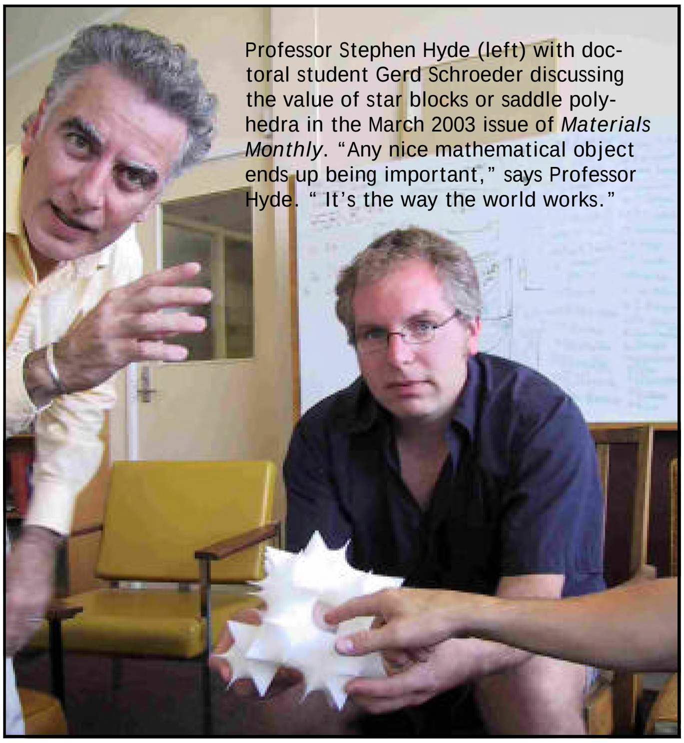
Professor Stephen Hyde

Professor Hyde, based in the Department of Applied Maths (RSPhysSE), is a well-regarded authority in complex materials. As part of the Fellowship, he will investigate self-assembly, responsible for the growth of complex multi-scale systems.

Complex systems, from biological ecosystems to financial markets and the Internet, are characterised by spontaneous clustering and linkages that determine their collective behaviour.

Professor Hyde's research will detail the geometry, topology, materials science and statistical physics of networks, leading to design and characterisation of robust self-assembled materials and complex systems.

ANU Vice-Chancellor Professor Ian Chubb congratulated Professor Hyde on the award, and said his interdisciplinary research would ensure ANU remained at the leading edge of physics and mathematics.



Professor Stephen Hyde (left) with doctoral student Gerd Schroeder discussing the value of star blocks or saddle polyhedra in the March 2003 issue of *Materials Monthly*. "Any nice mathematical object ends up being important," says Professor Hyde. " It's the way the world works."

Professor Jagadish stands behind Dr Hoe Tan as he prepares a silicon wafer for thin coating in the metal-organic chemical vapour deposition laboratory, one of the most sophisticated labs of its kind in the world. Professor Jagadish has been developing the lab since 1992.

"Professor Hyde has built an outstanding reputation and is uniquely qualified to develop a high profile Australian capacity in this important field," Professor Chubb said.

"There is no doubt that complex hybrid materials, including liquid crystals and fragile porous materials, are emerging as being one of crucial importance to advanced technologies, particularly nanotechnology, and Australia must cement its presence in this area at this highest level.

"This Federation Fellowship will help ensure, through Professor Hyde's research, ANU will remain at the forefront of this important area."

Professor Jagadish

Professor Jagadish, based in the Department of Electronic Materials Engineering (RSPhysSE), has been leading research in the science and application of semiconductor photonics and nanotechnology for a number of years, and has achieved world firsts in terms of novel processes, devices and their performance.

Professor Jagadish is the only Australian elected to Fellowships of both the Institute of Electrical and Electronic Engineers and the American Physical Society and has the highest number of publications in prime journals in the field of nanotechnology of any Australian.

ANU Vice-Chancellor, Professor Ian Chubb, congratulated Professor Jagadish on his prestigious Federation Fellowship.

"Professor Jagadish's proposed research on semiconductor nanostructures and photonics applications offers an entirely new approach to an area that is a hot topic of international interest," Professor Chubb said.

"It has potential for major discoveries as well as developing new technologies for future industries in Australia.

"Professor Jagadish is recognised as a world leading researcher in the priority areas of photonics and nanotechnology, and his work and this Federation Fellowship will continue to contribute to the University's wider aim of achieving excellence."

Making materials sing

(Continued from page 3)
the material of choice because the tube is too long (about 3 metres) to be economically made from silver. It is then usually silver plated for appearance sake. Again, the material makes little if any difference, and a French Horn made from garden hose actually plays quite well in the hands of a top-rank player!

Pluck those strings

String instruments are in another completely different class because, though the vibrating string is the source of all the sound, it cannot radiate any appreciable sound by itself because it is so small in diameter. It needs to communicate its vibrations to a much larger structure that will do the radiating for it. Here, then, the vibrational properties of this body will have a very large influence on the sound, and these properties are determined, as in the bell, by both the material and its shape. This does not mean that string material is unimportant, however, and gut or nylon strings sound "mellow" and metal strings "bright" because of the difference in high-frequency internal elastic damping.

Instruments such as the violin and the guitar have a hollow body with either one or two vent holes that provide a bass resonance, and the strings are connected to the thin upper plate through a bridge on which they rest. In the guitar the top plate is flat but braced internally, while in the violin the necessary stiffness is provided by giving the top plate a slightly domed shape. Sitka spruce is the preferred timber because it is about ten times as stiff to bending along the grain as to bending across the grain, and the square root of this number, which is proportional to wavelength, matches well with the elongated shape of the violin. The thickness, variation and arch must be individually crafted for each violin since every piece of wood is different.

The sound also depends on the vibrational losses at high frequencies, since they will make the sound "mellow" if they are moderately large and "bright" if they are small —a violin made from metal sheet would sound "tinny". Understandably there has been a lot of work done on the properties of wood for violins, and some Australian timbers have been found to be quite good for the "bright" style. One might have to let such an instrument mature for a few hundred years, however, to be able to compare the sound properly with that of a classic Stradivarius violin!

More info: Neville.Fletcher@anu.edu.au

Makers of the gong

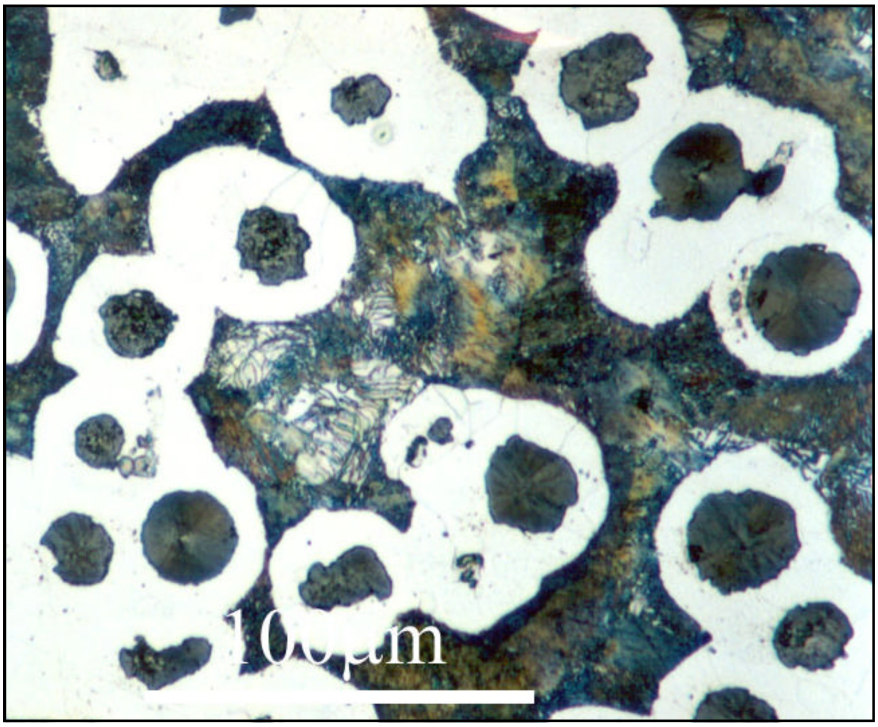
When University House decided to build a ceremonial gong to celebrate its 50th Anniversary, it turned to a team at the Research School of Physical Sciences and Engineering to actually build it. Neville led the way in designing the sound characteristics of the instrument. Here's an excerpt from an article he wrote on the challenges of designing a dinner gong. (If you would like a copy of the full article, please contact CSEM.)

A gong is generally intermediate in sound between a bell and a cymbal. A bell achieves its tonal quality by being cast to a highly curved shape with very thick walls, so that wall stiffness dominates the behaviour and makes it almost completely linear. The lower mode frequencies are well separated and clearly defined, and the bell maker spends much effort in tuning their relative frequencies to near-harmonic ratios. At the other end of the scale, a cymbal is nearly flat and has free edges. When struck close to the edge with a hard stick, many higher nodes with nodal diameters are excited and the sound is 'shimmering' rather than tonal.

A gong sound lies between these two extremes, and can vary widely from one design to another. The metal sheet from which the gong is constructed is thicker than that of a cymbal but thinner than that of a bell, and the edge of a gong is almost invariably turned down to stiffen it against high-frequency modes with nodal diameters. A gong is usually struck with a padded hammer so that the impact is spread over an appreciable area. This inhibits the excitation of very high-frequency modes.

For a dinner gong it is appropriate to maintain the gong pitch nearly level during the decay of the sound. One way of ensuring this is to make the gong from rather thick metal so the vibrational amplitude is always less than the metal thickness and the gong behaves almost in the same way as a bell. Another way is to make the gong with a domed shape and to ensure that the height of the dome is significantly greater than the greatest vibrational amplitude that will be achieved, as is done in bells. Which of these sounds is the more desirable can only determined subjectively by listening to the gongs.

▶▶ Builders of a ceremonial gong for University House: (from left) Tony Barling, Stephen Holgate, Steve Brooks, Neville Fletcher and Ron Cruikshank (all from RSPSE). Neville designed the gong's acoustic characteristics. See the May issue of ScienceWise for further details (http://ni.anu.edu.au/natinst/institute_publications.asp?aaid=60)



Pick the pic

The image shown here is a thin section of cast iron with magnesium induced spheroidised graphite. The spheroids range in size from 10-50 micrometres in diameter.

Cast iron is a brittle material and it is advantageous to process it in such a way to improve its ductility (ability to stretch and plastically deform without fracturing). The brittleness is partially due to the graphite flakes which act as nucleation sites for cracks. Therefore it's an advantage to have the graphite present as spheres. This can be achieved by a heat treatment or by the addition of a small amount of magnesium which poisons the graphite growth directions.

This image was taken by Dr R Cochrane from the University of Leeds, and is one of many materials images available in the DoITPoMS Micrograph Library run by the University of Cambridge. **(See: www.msm.cam.ac.uk/doitpoms/miclib/index.php).**

Not another acronym!

All through last year (and some of this year) you've heard *Materials Monthly* telling you about the AMTN (short for the Australian Materials Technology Network). Well, if after CSEM, ANU, RSPSE, RSC, RSES, JCSMR, RSBS (and not forgetting the EMU), your head is too full of letters to store another acronym then you'll be pleased to know that the AMTN has taken on a new and distinctive title. It's now known as **Future Materials**.

The new identity was officially launched at the end of May by the Federal Minister for Industry, Tourism and Resources, Ian Macfarlane (pictured left), at the University of Queensland. In his speech, Minister Macfarlane said he saw Future Materials as providing "an easy to use, cost and time effective interface for technology transfer between companies and the nest expertise and scientific facilities for advanced materials technology in Australia. In this way it links industry with research, especially SMEs, who often find it difficult to interact with universities."

Read all about Future Materials at its new website: http://www.future.org.au/

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

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

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