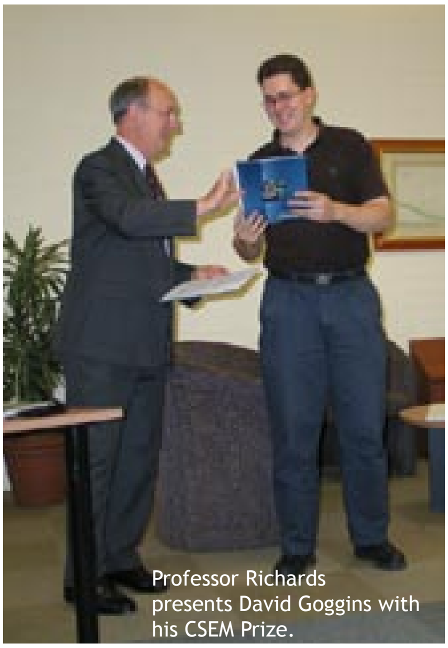
CSEM's
Materials Monthly
February 2005 Making materials matter

From nanocrystals to terracotta



Professor Richards presents David Goggins with his CSEM Prize.

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2004 CSEM Prizes

What do defects in silicon nanostructures have in common in with low-tech terracotta water filters? While they come from opposite ends of the technology spectrum, they are both studies in materials science and they were also both topics of winning undergraduate research projects in the 2004 CSEM Prizes.

The CSEM Prizes have now been running for three years. The award seeks to acknowledge excellence in materials science and engineering at an undergraduate level. There are two prizes, one for the best Honours thesis in the field of science of materials and one for the best thesis on the application of materials (as judged by an expert committee).

"In each of the three years it's been running the number and diversity of entries has increased," says Dr Zbigniew Stachurski, Director of CSEM. "The 2004 set of entrants is our best yet and they come for all over ANU. I believe that this is a very positive reflection on the health of materials science and engineering at an undergraduate level at ANU."

The winners of the 2004 CSEM Prizes were announced by Professor John Richards, Director of the RSISE, at an awards ceremony held in mid December.

"Wilson Pok from the Faculty of Science won the Science of Materials category," says Dr Stachurski. "Working at the Department of Electronic Materials Engineering at RSPSE, Wilson studied the optical and structural properties of silicon nanostructures after deforming them with mechanical and thermal shocks. This is research at the cutting edge of nanotechnology and is important in the development of new

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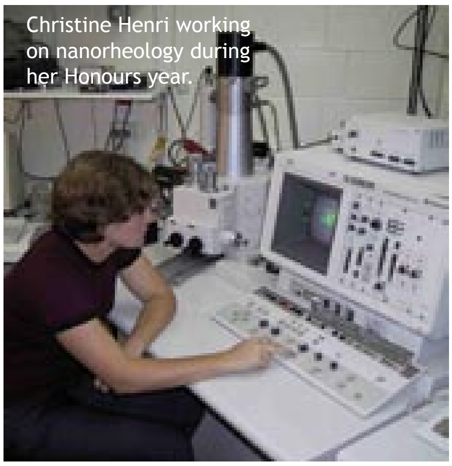
Holding on to our best and brightest

Here's a bit of good news about a CSEM Prize winner from 2003. Christine Henry won the award for best thesis, Science of Materials.

"She was a gifted and dedicated Honours student," says Dr Vince Craig from Applied Maths, one of her supervisors on the project. "Christine's research was on nanorheology: the science of rubbing surfaces on a nanoscale. She used a custom-built atomic force microscope to measure both static and dynamic force components concurrently as 2 surfaces come together.

"At that time Christine was studying for a science law degree and I believe she had several offers to join legal firms. I'm happy to announce that instead of pursuing law, Christine has elected to continue with science, and has just begun a PhD with Applied Maths in the area of nanorheology.

"I think it's important that we reward our best and brightest students at an undergraduate level," says Dr Craig. "It's a competitive world out there and the recognition that comes with awards like the CSEM Prizes are one important way of sustaining the interest of young scientists."



Christine Henri working on nanorheology during her Honours year.

From nanocrystals to terracotta

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optoelectronic devices.

"Our other prize, for Application of Materials, went to David Goggin from the Faculty of Engineering. David carried out pioneering work on developing an effective terracotta water filter for East Timorese villagers. He examined how local materials available to the villagers might be used to create simple filters to purify water. The applications of his research have important humanitarian outcomes.

"As you can see, the winning thesis come from different ends of the technology spectrum which simply demonstrates the diversity and value of materials science and engineering. We also had research projects on particleboards, child safety restraints, cutting edge theoretical chemistry and the electro-spinning of nanofibres.

David Goggin with a range of clay samples.

"Based on the growing popularity of the CSEM Prizes over the past three years I'd say it's proven it's value. What's more, I'm confident we can generate even more interest in 2005.

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Entrants in the 2004 CSEM Awards

Julie Kennett (Wood Workshop, Faculty of Arts) – 'Innovative new table design using plantation timbers'

Matthew Baker (Chemistry, Faculty of Science) – 'Experimental verification of the fluctuation theorem in a viscoelastic solvent'

Sarah Everett (Physics, Faculty of Science) – 'Formation and characterisation of amorphous gallium nitride'

Adrian Hawley (Chemistry, Faculty of Science) – 'Surfactant-based self-assembled transition metal oxide films'

Wilson Pok (Physics, Faculty of Science) – 'Mechanically and thermally induced defects in silicon nanostructures'

Reanna Albion (Faculty of Engineering & Information Technology) – 'Characterisation of GaAs nanocrystals'

Peter Blackert (Faculty of Engineering & Information Technology) – 'Application of advanced lightweight materials for optimisation of function and weight in vehicle platforms'

Suppakit Charvanichborikam (Faculty of Engineering & Information Technology) – 'Electrospinning of nanofibres'

David Goggin (Faculty of Engineering & Information Technology) – 'Development of a low-fired terracota water filter for East Timor'

Sven Holcombe (Faculty of Engineering & Information Technology) – 'Analysis and improvement of child restraint safety for side impact crashes'

Zo Lowrie-Nunes (Faculty of Engineering & Information Technology) – 'Characterisation of In0.5Ga0.5As QD lasers'

Olivia Morrison (Faculty of Engineering & Information Technology) – 'Resin distribution in particleboard'

Aaron Waters (Faculty of Engineering & Information Technology) – 'Finite element analysis and optimisation of paralympic wheelchair wheels'

The 2004 Judging Committee: Dr Zbigniew Stachurski (CSEM), Professor Elmars Krausz (RSC), Dr Paul Compston (FEIT), Professor Andres Cuevas (FEIT) and Professor Aidan Byrne (RSPSE).

The shape of things to come

Shape memory alloys (SMAs) may be the driving force behind a new generation of devices thanks to work by engineers at the Research School of Information Sciences and Engineering. By exploring innovative ways to control shape memory alloys the engineers have been able to dramatically improve the speed and accuracy of actuators driven by SMAs.

Shape memory alloys are mixes of nickel and titanium that can remember a shape and return to it as the temperature changes. When heated, wires can be made to rapidly shorten by up to 5% of their length, and then lengthen when cooled. This capacity to contract and relax has led to shape memory alloys often being referred to as 'muscle wire', Which is very appropriate because when shape memory wires are arranged in antagonistic pairs, and connected to a pulley, the contraction of one wire will rotate the pulley and also stretch the other wire. This is just like muscles in real life where the movement of an arm or a leg is controlled by the contraction of a muscle. As a muscle contracts on one side, a muscle on the other side relaxes and is stretched open.

By controlling the motion of pulleys with muscle wires you've effectively created an actuator, a device that performs a mechanical action, and there are many situations where actuators based on shape memory alloys have big advantages over actuators based on electric motors. Shape memory alloys are already in use in a range of medical, industrial, robotic and household devices. Their advantages include mechanical simplicity, high power-to-weight ratio, small size, and clean, silent, spark-free operation.

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Improving SMAs

"Shape memory alloys are useful for producing motion, especially in confined spaces where there is not enough room for an electric motor," says Dr Roy Featherstone. "Unfortunately, with present technology, their motions are slow and difficult to control."

Dr Featherstone heads the Fast SMA Motion Project in the Department of Information Engineering, RSISE. Working with PhD student Yee Harn Teh, Dr Featherstone believes they may have overcome these problems.

"In principle, one only has to heat the shape memory alloy to make it move," says Dr Featherstone. "The tricky part is to apply exactly the right amount of heating, at exactly the right moment, in order to produce the desired motion."

The heat is actually generated by passing a current of electricity through the SMA wire. The traditional approach has been to limit the current to a level that won't damage the wire. Unfortunately, this creates a lag between when the current is switched on to when the wire contracts.

Dr Featherstone's group has used higher levels of current but cut it back before it damages the wire. The trick is to measure the resistance of the wire and use this as a guide to whether the SMA might be overheating.

Researchers elsewhere have measured the temperature of the wire with a thermocouple. When the desired temperature, and corresponding contraction, is reached the current is switched off and the other wire in the antagonistic pair is then heated.

"Measuring the temperature of these SMA wires takes a lot of effort. These are very fine wires we're talking about and attaching accurate instrumentation to them is messy," explains Dr Featherstone.

"Our approach has been to measure the electrical resistance in the wire. This can be measured directly from the current being fed into the wire. It doesn't require extra instrumentation and provides a precise and instantaneous measure of what's happening with the SMA.

The remarkable SMA loudspeaker

There is a common perception among many people that shape memory alloys cannot respond quickly to rapid fluctuations of temperature. Dr Featherstone's group has comprehensively disproved this by building a deceptively simple loudspeaker system based on a light plastic cup suspended between a 0.1mm SMA (Flexinol) wire, attached to the back of the cup, and a pair of elastic bands, a piece of string and a small weight, attached to the front. The weight ensures an approximately constant tension on the SMA wire; and the cup does not touch the wooden frame below it.

The SMA is fed a heating current consisting of an audio signal and a DC bias just sufficient to ensure that the current is always positive. The result is a quiet, but plainly audible, sound. In particular, frequencies well above 1 kHz can be heard.

The point of this experiment is to demonstrate that SMAs are capable of responding to a change in heating current in less than a millisecond. If you don't believe this is possible, visit Dr Featherstone's website at http://rsise.anu.edu.au/~roy/SMA/ and listen to the theme from Mission Impossible, recorded via their very own SMA speaker.

"We've tested this approach in a device called a pantograph. The pulleys attached to the SMA wires control the movements of two connected robot arms. The contraction of the SMA wires is controlled by measuring the electrical resistance in the SMA wires. We've demonstrated that this approach allows for movement significantly faster than has been achieved by any other system."

To be precise

The other problem with SMA actuators has been the lack of precision of the movement it can perform.

"We've overcome this problem, too," says Dr Featherstone. "The solution here is through modifying the control program.

"As the pantograph robot arms are moved by the pulleys (attached to the SMA wires), their positions are constantly monitored and the distance between where they are

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A simple pantograph robot, actuated by two antagonistic pairs of shape memory alloy wire. The pantograph arms are at the top of the photo. Each arm is connected to a pulley which are controlled by the SMA wires.

Shape shifters

Shape memory alloys can rapidly change shape because they have two crystalline states or phases at different temperatures. One phase is stable at low temperatures, and the other is stable at high temperatures. A typical shape memory alloy can be deformed easily in its low temperature phase, but will return to its original shape when heated. Depending on how you set it up, the material can be made to contract forcibly when heated and then be stretched easily as it cools.

Just over the hill from ANU as you head towards the airport lies the Australian Defence Force Academy (ADFA). Within the Academy is a college established by the University of NSW. Known as UNSW@ADFA, the college conducts university courses for officer cadets and officers of the Australian Defence Force. Contained within the School of Physical, Environmental and Mathematical Sciences (one of five schools at UNSW@ADFA) is the Advanced Materials group. Led by Professor Stewart Campbell, Dr Wayne Hutchison, Assoc Professor Glen Stewart and Dr Heiko Timmers, the group has developed extensive capacities in a number of areas of materials research including working with radioactive probes, Mössbauer spectroscopy and low temperature work. Several collaborations with scientists at ANU exist, however, there's scope for more interaction. This special profile of materials research at UNSW@ADFA aims to inform CSEM members of some of their research.


Heiko Timmers (centre) with colleagues Wolf-Dietrich Zeitz (left), and Santosh Shrestha discuss the magnetism of nickel

Nuclear spies at UNSW@ADFA

In order to gain inside information on materials, the UNSW@ADFA Advanced Materials research group relies on its spies - nuclear spies that is.

Nuclei energy levels are extremely sensitive to the local atomic environment and a range of experimental techniques can be used to tap into this information. The spy nuclei can be indigenous to the material, or they can be introduced as foreign agents by means of diffusion or ion implantation.

Radioactive nuclei are particularly useful as such probes because gamma-ray emission provides an efficient means of communicating information to the outside world. Australia's only low energy, radioisotope implanter is located at UNSW@ADFA. It has been developed as a collaborative project together with ANU.

The radioactive spy nuclei are often combined effectively with cryogenic platforms that provide controlled temperatures ranging from very low all the way through to room temperature. The $^3He/^4He$ dilution refrigerators at UNSW@ADFA have base temperatures of 5 milli kelvin and allow specimens to be "top-loaded" with a recovery time of just a few hours.

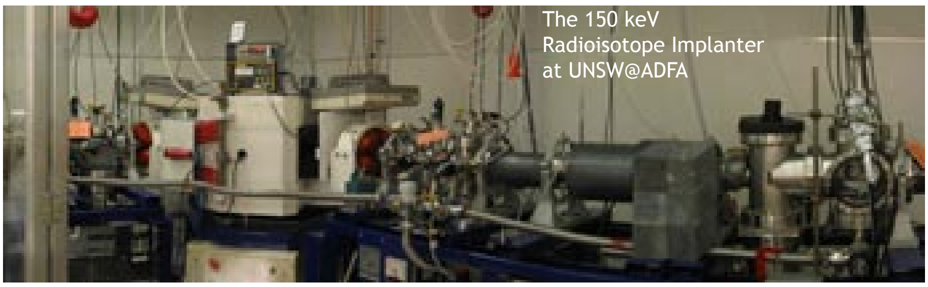
So what is the UNSW@ADFA Advanced Materials research group spying on? Most of the research focuses on characterising the electrostatic and magnetic interactions at the atomic scale that are responsible for the interesting and useful bulk behaviour of materials. Semiconductor materials and rare earth compounds are of particular interest.

Materials for stealth

One of Glen Stewart's projects has an applied bent in that it looks at doped ferrites as potential radar absorbing materials (or RAM's). The highly publicised 'stealth' bombers are coated with radar absorbing tiles. However, RAM tiles can also be exploited on sea- and land-based installations that require invisibility to long-range radar.

In the case of the ferrites under investigation, the ferromagnetic resonance (responsible for the absorption) can be dragged down into the conventional radar bands by replacing some of the iron with other combinations of elements. The rate at which this frequency drops depends on both the dopant combination itself and the particular iron sites that the dopant atoms end up in. Iron-57 Mössbauer spectroscopy is well-suited to uncover such information. The microwave network analysis determinations of the materials' electromagnetic properties are conducted in collaboration with DSTO at its Maribyrnong site (Melbourne).

The ferromagnetic resonance frequency is directly related to the bulk property of magnetocrystalline anisotropy, or the degree to which the magnetisation prefers to line up with a particular direction of the crystal structure. This is a key parameter for researchers looking for new data storage media. It is intriguing that researchers in the two fields (RAM's and data storage) usually seem unaware of the research being undertaken by their counterparts in the other field.


The 150 keV Radioisotope Implanter at UNSW@ADFA

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More from magnetism

Today's technology-based society relies on magnetic materials to an extent unimaginable even as recently as 20 years ago. Their applications range from the trivial (but useful) refrigerator magnets to the ubiquitous computer, recording media, mobile telephones, and scanning and imaging devices (based on superconducting magnets).

Rare-earth (R) transition-metal (T) intermetallic compounds are among the most important magnetic materials currently available. They are the basis of the world's strongest magnets, and have many applications. For example $SmCo_5$ exhibits the largest known uniaxial anisotropy at room temperature (17.2 MJ m^{-3}) with $Nd_2Fe_{14}B$ displaying the largest energy product (445 kJ m^{-3}). The microstructure of these materials can be controlled by suitable treatments to change and optimise their overall magnetic behaviour. As examples, Nd-Fe-B magnets are used in CD-ROM drive units and disc drives in computers in addition to a myriad of applications in multi-purpose electronic equipment.

Despite these impressive technological and commercial developments, numerous aspects of rare-earth magnetism remain to be developed and resolved. This is the exciting point at which the research of Stewart Campbell and his collaborators comes in. In addition to searching for new materials, they study the interplay between the fundamental magnetic exchange and crystal field interactions responsible for superior magnetic performance. Extra flavour and insight

Mössbauer spectroscopy

Mössbauer spectroscopy is named after Rudolf Mössbauer, a German physicist who researched the absorption of gamma-rays by matter and developed the basics of spectroscopy using gamma-rays.

Gamma-rays that are emitted from an oscillating source of radioactive nuclei are passed through a thin specimen (the 'absorber') and monitored as a function of the source's velocity. When the Doppler-shifted gamma energy matches that of a transition in the absorber nuclei, a telltale dip in count rate is registered.

An alternative configuration employs dilute concentrations of radioactive nuclei in the specimen material and an oscillating reference absorber. In fundamental applications, the technique studies processes at the atomic level. In a more general approach, it can be used to 'fingerprint' and quantify the amounts of microscopic phases present.

The Mössbauer resonance most commonly employed at ADFA is the 14.4 keV transition of Iron-57. However, the 8.4 keV resonance of Thulium-169 is also employed for studies of lanthanide compounds.

is provided by the ability to both prepare new samples and by measuring both their macroscopic magnetic properties and the microscopic interactions.

The measurement techniques include: x-ray diffraction for sample characterisation; magnetic studies over wide temperature ranges (typically 4.2-300 K) for both alternating and steady magnetic fields; and Mössbauer spectroscopy. Besides experiments at UNSW@ADFA, neutron diffraction measurements are carried out at the HIFAR reactor at Lucas Heights, and overseas. The key feature here is that despite its zero net charge, the spinning neutron with its non-symmetric charge distribution results in a magnetic moment, so the experiments give crystal and magnetic structural information.

From left to right: Glen Stewart, Nakorn Suwuntanasarn (Wayne's PhD student) & Wayne Hutchison in front of one of the two UNSW@ADFA 3He-4He dilution refrigerators.

It is then by pulling the results of all of these measurements and analyses together that a pretty complete impression of the underlying physics is obtained which accounts for the observed behaviour, particularly the critical interplay between the rare-earth and transition-metal sublattices in ternary compounds. This allows the understanding of complex compounds, including the series of novel quaternary compounds $R_3T_{29}Si_4B_{10}$ (R = rare-earth elements La to Lu; T = Co, Ni) that have recently been discovered as part of this work. Indeed, this discovery has opened up a new area of rare-earth magnetism with over 70 new compounds being added to the rare earth family.

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Deep inside nickel

We use iron, cobalt and nickel permanent magnets all the time. They are so familiar and yet many aspects of their structure and function are still not well known. While everyone will have explored and played with the attractive strength of a horse shoe magnet, it is much more challenging to measure this strength at the atomic level. In fact, it is not entirely clear what happens to the magnetic field when atoms are missing in the regular lattice arrangement of a magnet.

Experiments to study this have recently been performed at UNSW@ADFA by Heiko Timmers and collaborators. With the unique low energy, radioisotope implanter, the radioactive nucleus Indium-111 was introduced into nickel foils to probe the magnetic field right between the nickel atoms.

While most of Indium-111 probes find their way onto vacant sites in the nickel lattice, some will move into voids, where more than one nickel atom is missing. The violent implantation of the probes in fact creates some of these voids. Once in place, the magnetic moment of the probe nucleus, which may be visualized as a tiny compass needle, reacts to the local magnetic field at its position. Strong fields cause this 'needle' to react dramatically, while small fields result in a more gentle response.

Stewart Campbell with colleagues and students. Back row from left: Mark Whitty, Stewart Campbell, Jianli Wang and Finn Kelly. Front row from left: Steve James and Vern Edge.

The response of the magnetic moment is reflected, and thus reported back to the experimenter, by the spatial correlation between the two gamma-rays which are emitted following the radioactive decay of the Indium-111 probe. This is not unlike a spy sending intelligence to home-base using two pigeons. The reception of the pigeons, or in this case the detection of the two gamma-rays, reveals the desired information about the otherwise inaccessible location.

The experiments are quite a feat since the probe nuclei, which have a life time of only a few days, are made in Boston, USA. They are then shipped half around the world before some one hundred billion of them are introduced, one by one, as negatively charged InO ions into the nickel samples.

The experiments indicate that the magnetic field inside voids and vacancies in nickel is determined by the number of next atomic neighbours. Surprisingly, the distance to these neighbouring atoms barely plays a role.

Similar experiments are carried out by the researchers with the aim to characterise semiconductors such as InN and InGaAs which are developed and improved for optoelectronic applications. In particular the formation and curing of lattice vacancies is being studied. Since vacancy defects affect the electron mobility of a semiconductor, such work is crucial for the future technological exploitation of these materials.

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Spies at low temp

The energetics of nuclear magnetism correspond in thermal energy terms to millikelvin temperatures. The UNSW@ADFA group has built a reputation for expertise and innovation in the use of radioactive nuclei to probe magnetism, magnetic order and

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The shape of things

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added instructions that ensure that the wires controlling each pulley are under a small degree of tension even when the robot arms are exactly where they should be."

Initial applications for this improved technology are likely to be in precision medical devices, such as steerable endoscopes and catheters, which already use SMA actuators. However, the new control system would make the devices more responsive to motion commands.

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UNSW@ADFA

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finer detail of crystal structure using low temperature nuclear orientation and associated millikelvin magnetic resonance techniques. The sensitivity of these techniques allows the probing nuclear spies to be either extremely dilute and non-perturbing in case of bulk samples, or part of a truly low dimensional structure.

The radioactive signature also allows for use of more than one different type of nuclear probes concurrently. Wayne Hutchison and co-workers have studied the magnetism in an array of rare earth intermetallic alloys via the millikelvin techniques using different rare earth probes to reveal unique structures for various rare earth ions.

The interaction of nuclear magnets with a magnetic field is one of a large number of quantum mechanical systems under consideration as the basis for a quantum computer. Such a computer would have phenomenal power in factorisation, encryption and deciphering.

Phosphorous nuclei placed in silicon and cooled to millikelvin temperatures are being considered as a possible quantum computer. Wayne and Nakorn Suwuntanasarn are interested in putting such phosphorous nuclear spies through their paces as potential code breakers.

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More info on the Advanced Materials Group at UNSW@ADFA: http://www.unsw.adfa.edu.au/pems/research/adv_materials.html

Pick the pic

What a blast

This high-speed photograph shows the blast wave generated by a small explosive charge, which was ignited by the pulse of a laser.

You can see the blast itself as well as the reflected waves from a nearby wall, and a cloud of combustion products. The photograph was taken 120 microseconds, or 120 millionths of a second, after ignition.

This image combines two methods of flow visualisation: holographic interferometry and colour schlieren. The interferogram shows density distributions as black 'fringes' while the schlieren record reveals the density gradient in different hues. The two images can be analysed individually or superimposed, as in this case.

The image was provided by Dr Harald Kleine, School of Aerospace, Civil and Mechanical Engineering, Australian Defence Force Academy, and appeared in Kleine, H. & Takayama, K. 2001, Combined shlieren and interferometry visualization of blast waves. *Phys. Fluids* 13 (9), S4.

This image also appeared as part of *flowvis,* an exhibit showcasing the amazing world of fluid dynamics. *flowvis* was staged in the Foyer Gallery of the ANU School of Art at the beginning of February (as part of the 16th Biennial Congress of the Australian Institute of Physics). *flowvis* was conceived and produced by Melanie O'Byrne, a doctoral student at the RSES.

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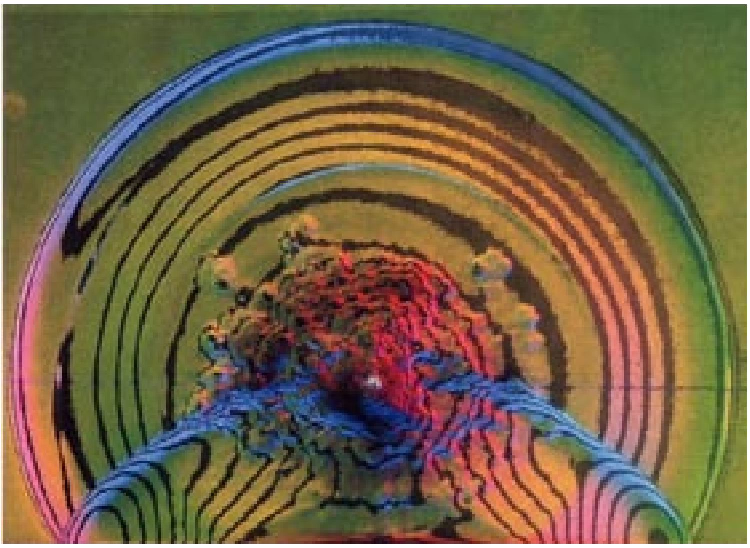

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