ANU Centre for Science and Engineering of Materials

Materials Monthly

Making materials matter

October 2002

Up, up and away with

Ultra-fast photodetectors

by
Christine Carmody

▲▲ Christine extracting a sample wafer of indium phosphide from the MOCVD reactor (see Sept MM, p3, for details on the MOCVD).

Optical communications have come a long way since the first laboratory demonstrations of the laser in the early 1960s, however the technological revolution is far from over. Indeed, in some areas such as semiconductor photodetectors, it's only just taking off, and research at RSPhysSE's Department of Electronic Materials Engineering is making an important contribution to the field.

Lasers, together with low-loss optical fibre, heralded a boom in optical communications research. By the early 1980s, the first optical communication systems had been deployed commercially. These early systems had data rates comparable to the best electrical and radio transmission of the day (in the tens of Mbit/s range), and boasted reduced costs associated with the ability to transmit light signals over relatively long distances in optical fibre.

As the speed of digital electronics increased, these technologies were applied directly to increasing the speed of optical transmission systems. By the late 1980s, commercially deployed optical systems had data rates exceeding1 Gbit/s, and these days, approximately 5 billion megabytes per month flash across the globe inside optical fibres. Within the last few years, the demand for bandwidth has skyrocketed, fuelled in part by the growth of data traffic on the Internet. Consequently, everything that's in the business of connecting us is striving to keep up.

My investigation into materials for ultrafast photodetectors was conceived with exactly this in mind. To transmit and detect optical signals at the long wavelengths used by optical fibres, indium phosphide (InP) and indium gallium arsenide (InGaAs) are the semiconductors of choice. A little over a decade ago, it was discovered that in some semiconductors (such as GaAs), if the wafer was grown at low temperatures or bombarded with high energy ions, a material was produced that could detect an optical pulse and be ready to receive the next one in less than one picosecond (10^{-12} second, or one trillionth of a second).

I have found that ion bombardment of InP and InGaAs will also result in a very fast material, but with a drawback caused by the electrical configuration of the defects the process introduces into the crystal lattice.

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Ultra-fast photodetectors

This drawback is a high ‘leakage current’, which is due to a large number of free electrons ‘donated’ by the defects. A high leakage current is undesirable because it interferes with the normal operation of the device, it can drown the desired electrical output with noise, and it causes heat fatigue which can significantly reduce the lifetime of the device (if not render it inoperable).

I have been able to get a fast optical response in InP and InGaAs, as well as very low leakage currents, by implanting the semiconductor with iron (Fe). The electrical configuration of Fe impurities in these semiconductors results in deep energy levels. These deep levels behave as traps for the free electrons (donated by various other defects which are also created by the implantation) that are responsible for the unwanted leakage current. So far I've produced ion-implanted InP samples with a response time as low as 130 femtoseconds (10^{-15} second).

Devices using this material would have a bandwidth as high as 8 THz. Our existing communications systems operate at 10 GHz, and the next upgrade to 40 GHz is soon to be deployed worldwide.

In the meantime, research into fast response optoelectronic devices continues, and new ways of squeezing faster performance out of these materials are constantly being devised.

For more information on the history of optical communication systems, see: The Roads and Crossroads of Internet History by Gregory R. Gromov (at http://www.netvalley.com/intval1.html). For more information on InP and InGaAs based photodetectors, contact Christine (cyc109@rsphy1.anu.edu.au) or look at the Department of Electronic Materials Engineering website (http://wwwrsphysse.anu.edu.au/School_Pages/dep_eme.html)

Editor’s note: Christine is a graduate student working with Prof Jagadish in the Department of Electronic Materials Engineering. I met Christine when I was given a tour of the MOCVD reactor (see the September issue of MM, p3), and asked her to write me a short article on her area of research (which appears here).

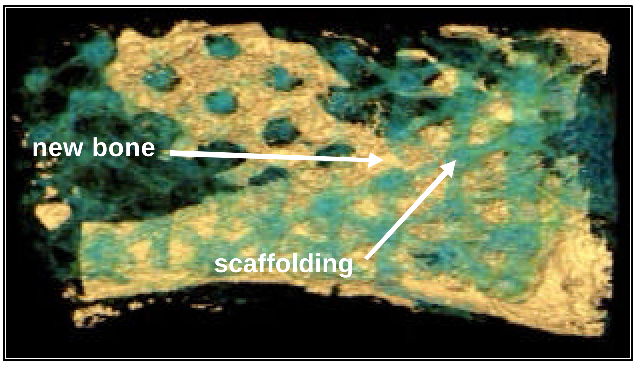
It’s great to see graduate students discuss their area of materials science, and I would encourage other graduate students to consider providing me with short stories on what they do.

Supervisors, if you have a student whose research warrants sharing with the broader ANU materials science community, please let me know (I’m happy to chase it up).

Insights on bone scaffolding

‘Body—heal thyself’ is the mantra of the tissue-engineering crowd as they devise a host of new techniques for creating polymer scaffolding around which the body’s tissues will grow. And new materials characterisation equipment at ANU is providing invaluable insights on what’s happening around the scaffolding.

A group of biomaterial researchers at the National University of Singapore (led by Dietmar Hutmacher) have developed novel 3D porous ‘scaffolds’ to provide a framework for the attachment and proliferation of osteoblastic (bone) cells in the eye sockets of pigs. To characterise what’s happening around the scaffolding conventional 2D histology is used but this doesn’t supply an in depth understanding of the bone mineralisation mechanism in three dimensions. A three dimensional analysis has the advantage of providing extra spatial information about the distribution and connectivity of the mineralised regrowth.

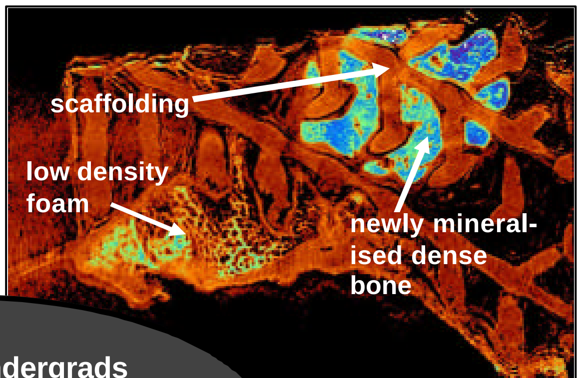


▲▲ CT image of bone graft showing polymer scaffold and newly mineralised bone.

The recently commissioned micro-CT (Computer Tomography apparatus, see Materials Monthly, April 2002) at Applied Mathematics (RSPhysSE) is in a unique position to provide 3D tomographic data on the micron scale.

Partially mineralised tissue/polymer composite bone grafts were sent to ANU where they were imaged (80kV, ~ 10 X mag., 10s exposure, 1800 projections) and reconstructed by fourth year Engineering Honours student, Anthony Jones (as part of his final year thesis). The resulting tomogram was filtered and segmented, and shows that the regions of highest density, indicating newly mineralised bone, were concentrated towards the core of the scaffold.

However it was noted large regions of the pore space remained un-mineralised. An area of lower density with fine foam-like morphology was resolved along the edge of the scaffold, possibly indicating a precursor to mineralised tissue. The overall structure is guided by the shape of the scaffold, which is unlike natural bone structure. The micro-CT has demonstrated its capability to image micron scale biomaterials and further studies are planned in the near future.

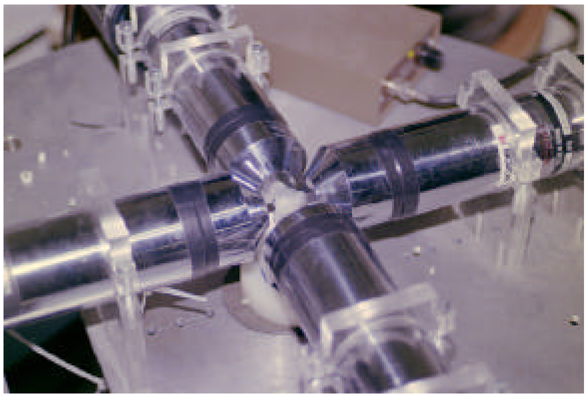


▲▲ A slice of the bone graft tomogram

Attention all undergrads & supervisors

This study qualifies for entry into the CSEM Prizes. Maybe your project/thesis does too? See page 4 for details.

PAC lab



▲▲ An array of four barium fluoride detectors are used to detect radiation from the probe nuclei.

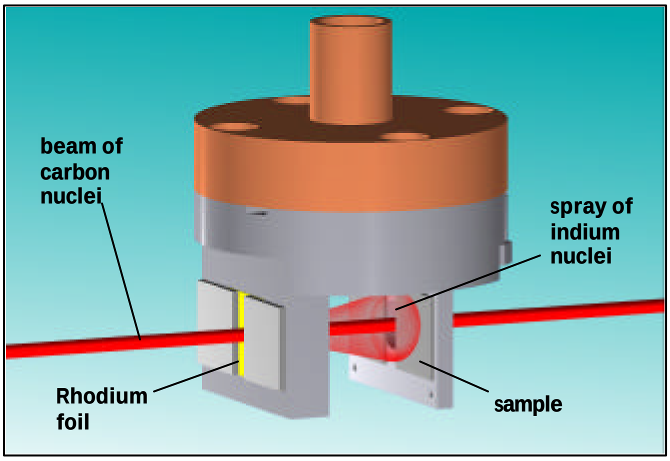
Characterising semiconductors with radioactive probes

ANU possesses specialist expertise in the area of using radioactive probe atoms to characterise semiconductors, a hyperfine technique known as Perturbed Angular Correlations or PAC. The radioactive atoms are created with the giant 14UD particle accelerator, part of the Heavy Ion Facility operated by the Department of Nuclear Physics.

The fabrication of semiconductor devices is increasingly dependent on the semiconductors being implanted (or doped) with ions. The process involves the semiconductor wafer being placed in an ion implanter where charged ions are fired at it. As a result, a portion of the ions becoming lodged in the semiconductor crystal. The implanted ions change the material properties of the semiconductor. The nature of the change depends on what type and concentration of ions are used, and what disorder is created in the semiconductor during the process of implantation.

Understanding what disorder is introduced to the crystal lattice of the semiconductor during implantation is critical to producing semiconductors with predictable behaviour. A variety of techniques can be used to characterise the crystal lattice including for example studies of X-ray absorption (EXAFS), backscattering of nuclei (RBS) and the use of radioactive probe atoms to study the internal electronic and magnetic structure of the lattice (PAC). No single method provides a full characterisation, however, together they provide a wealth of information on the properties of the crystal structure of semiconductor.

The nuclear hyperfine method of Perturbed Angular Correlations (PAC) uses radioactive atoms at very low concentrations implanted into the semiconductor being studied. The method relies on the change in the radiation pattern observed when an excited nucleus decays. Differences in these patterns reflect the different microscopic structure found at the site of the radioactive nucleus. .



▲▲ Implanting radioactive nuclei into a semiconductor sample involves striking a thin rhodium foil with a beam of carbon nuclei to generate radioactive indium nuclei. These spray out of the back of the foil and become lodged in the semiconductor sample mounted behind the foil.

The method employed at the Heavy Ion Facility works like this: a beam of carbon ions is accelerated by the 14UD tandem accelerator. The beam strikes a thin (2.5 um) foil of rhodium. This produces a small amount of radioactive indium atoms that spray out the back of the foil and strike a semiconductor sample mounted some 2 cm behind the target foil. Up to 60% of all the radioactive indium nuclei that leave the target foil can be collected on the semiconductor sample, coming to rest within 1 to 2.5 microns of the sample's surface.

After implantation with the radioactive atoms, the semiconductor is thermally annealed (at 800^0 for 10 seconds) to repair any damage to the crystal lattice caused by the implantation process. Off-line PAC measurements on these annealed samples confirm that the samples are returned to an undamaged state.

The semiconductor, now containing radioactive probe atoms, is then implanted with dopant nuclei in the 1.7 MeV ion implanter in the Department of Electronic Materials Engineering.

Radiation spectra being emitted by the probe nuclei are then measured using an array of four barium-fluoride scintillation detectors arranged in a plane around the sample.

Crystal defects in the semiconductor lattice, introduced during implantation, produce large electric field gradients around the probe nucleus. These electric field gradients perturb the distribution of radiation being emitted by the radioactive probe atoms. By measuring the amount of perturbation, it's possible to map the local electronic environment around the defects.

Another way of introducing radioactive probe nuclei into semiconductor materials is by using commercially available radioactive isotopes that are incorporated into the semiconductor in purpose-built ion implanters. The Australian Defence Force Academy (ADFA) in collaboration with ANU has developed a 150kV ion implanter which is housed at ADFA. The implanter was completed in 1998, and will shortly be ready for use with radioactive isotopes.

More information: aidan.byrne@anu.edu.au

Opportunities

◀•▶CSEM Prizes ◀•▶

Attention all undergraduates currently finishing off their final year thesis. Does your thesis have anything to do with materials science or applications of materials? If it does, why not enter it for a CSEM Prize.

You could win $2,000! and all you have to do is submit a copy of your thesis to the Director of CSEM by the end of November.

Two awards are on offer:
best thesis in the field of **Science of Materials**, and

best thesis in the field of **Application of Materials.**

The hard bit was doing the thesis, making one extra copy is simple, so why not give it a go.

Winners will receive a certificate, a cheque for $2,000 and publicity. What a great way to finish off a challenging year.

In order to be eligible for the prizes students must be enrolled in a program leading to the award of a degree of Bachelor offered by ANU.

For the full set of conditions, see
http://www.anu.edu.au/CSEM/Prizes.htm

But remember, the closing date for submissions is

30 November, 2002.

◀•▶CSEM Prizes ◀•▶

CEDAM Workshops

ANU Centre for Educational Development and Academic Methods (CEDAM) offer a range of educational and training opportunities perfectly suited to academics and researchers looking to improve their performance.

Here are some up coming workshops.

Supervising Research Students

Wednesday, 13 November, 2002; 9am -1pm
The workshop will include:

- ▶an opportunity to clarify individual expectations of the supervisory role
- ▶a panel presentation of supervisor and student perspectives
- ▶an exploration of the supervisory process
- ▶a presentation on university policy

Seminar & Conference Presentations

Course dates tba
This program of five 2-hour workshops provides training and coaching in the key elements of an effective professional presentation on your research work. The workshop series will be of value to both new and experienced academic staff.

Ways of Seeing, Teaching and Learning: inquiry, information literacy and curriculum

Tues, 26 November, 2002; 12-2pm
Presented by Christine Bruce followed by a panel chaired by Malcolm Gillies

More info: http://www.anu.edu.au/cedam/

Conferences / Seminars

◀✧▶ **Geology Seminar: The ZrO2-TiO2 system at various pressures New experimental data and implications for rocks and ceramics, Ulrike Troitzsch** — **4 November**
David Brown Lt, Geology Depart (Bld no. 47)

◀✧▶ **NIEIS Seminar: Solar Power/Stellar Future, Prof Andrew Blakers** — **6 November**
12.15pm, SAS Vision Theatre, National Museum of Australia
More information: http://www.rsise.anu.edu.au/nieis/blakers_abstract.html, heather.slater@anu.edu.au

◀✧▶ **Bioceramics 15** — **4-8 December**
15th International Symposium on Ceramics in Medicine
University of Sydney, More information: http://www.azom.com/details.asp?ArticleID=1321

◀✧▶ **COMMAD 2002** — **11-13 December**
2002 Conference on Optoelectronic and Microelectronic Materials and Devices
University of NSW, More information: http://www.commad.unsw.edu.au/

◀✧▶ **Smart Materials, Nano– and Micro– Smart Systems** — **16-18 December**
International Symposium, RMIT
More information: http://www.spie.org/conferences/calls/02/au/

◀✧▶ **The New Cosmology** — **3-14 Feb, 2003**
16th International Physics Summer School
ANU, More information: http://www.mso.anu.edu.au/newcosmology/

◀✧▶ **AMAS VII** — **18-20 Feb, 2003**
The Biennial Symposium of the Australian Microbeam Analysis Society
University of Melbourne, http://www.microscopy.org.au/amas/Symposium_HomePage.html

ANU Workshop on Nuclear Techniques

The second annual Workshop on Nuclear Techniques was held last month during the teaching break at the ANU's Heavy-Ion Facility. This workshop provides an opportunity for undergraduate students to get first hand experience in the methods of nuclear measurements and in the use of large accelerators.

Over 20 students participated in this year's workshop including a large contingent from the University of Wollongong's Medical Physics program as well as students from the ANU and ADFA. The program's convenor, Dr Aidan Byrne, said that one of the most pleasing features of the workshop was that almost half the students attended the program last year and chose to forgo their holidays and to return again this year!

The weeklong program is designed to actively engage students in the fundamentals of the measurements of nuclear radiations and the elements of isotope production using accelerator facilities. Senior students were required to design and implement a method to produce an isotope of their choice and to then to establish that they had indeed produced it! All students had the opportunity to use the heavy-ion accelerator as well as state of the art detector systems.

▲▲ Students Tamara Molloy and Christine DePlater, both from the University of Wollongong, mount a target for irradation using the Heavy-Ion facility.

A number of lectures were interspersed throughout the week, including talks presented by members of the Department of Nuclear Physics on accelerator technology by Dr David Weisser, gamma-ray detectors by Dr Greg Lane, gas detectors by Dr David Hinde and nuclear reactions by Dr Anna Wilson. Prof. Anatoly Rozenfeld from the University of Wollongong also presented a lecture on solid state strip detectors.

The workshop has become a regular feature on the Department of Nuclear Physics' program of events and anyone interested in attending next year workshop should get in touch with Dr Aidan Byrne at the Department of Nuclear Physics.

More informations: Aidan.Byrne@anu.edu.au

ARC Linkage Projects

ANU fared well in the latest round of Australian Research Council grants announced in October. Materials science in the Department of Engineering did particularly well with three major Linkage Projects getting the green light.

▶ Dr Andres Cuevas from the ANU Department of Engineering linked up with Dr Saul Winderbaum from BP Solar to snare a sizable Linkage's grant of $610k over three years for work on performance limitations in multicrystalline silicon solar cells.

The project, aims to address the major impediments to improving the efficiency of multicrystalline silicon solar cells, the most prevalent in industry today. Three key areas have been identified: understanding the fundamental source of carrier recombination in this material, the application of plasma silicon nitride to reducing this recombination, and developing a suitable technique for texturing the front surface of the cells. By using novel, advanced techniques to gain a deeper physical understanding of these issues (such as lifetime spectroscopy, see *MM*, May 2002), it will be possible to develop new, cost-effective processes that improve efficiency.

▲▲ Winners are grinners: Andres Cuevas won a major ARC grant to improve multicrystalline silicon cells.

▶ Prof Andrew Blakers, Dr Klaus Weber, Dr Mat Stocks from the Centre for Sustainable Energy Systems (Department of Engineering) together with Dr Pierre Verlinden from Origin Energy were awarded $620k over four years to produce low cost photovoltaic modules through reduced silicon consumption.

The project aims to develop new methods and processes for the production of solar cells and photovoltaic modules. The modules will be made from very thin, narrow silicon solar cells. Because the modules use much less silicon than conventional modules, they're expected to be substantially cheaper. Its expected the project will lead to implementation of the proposed technology in a pilot plant and commercialisation thereafter.

▶ Dr Shankar Kalyanasundaram, Prof Mick Cardew-Hall and Dr Paul Compston from the ANU Department of Engineering together with Professor Wesley Cantwell from the University of Liverpool (UK) were awarded $213k over three years to improve the stamp forming properties of lightweight fibre-metal laminate systems for the manufacture of motor vehicles.

The project, being carried out with Ford Motor Company, looks at the ability to form fibre metal laminates for automotive applications. These hybrid material systems have significant advantages over straight metal in terms of strength, weight, noise and impact reduction. The major research issue addressed here is how can such materials be formed for volume production.

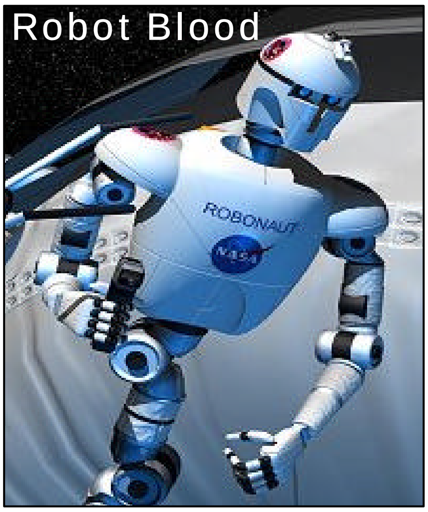
ANU also fared well in the ARC Linkage Infrastructure Equipment and Facilities grants, details of which will be discussed in a future issue of *Materials Monthly*.

MM webspotting:

Some Australian EMUs

- **ANU Electron Microscope Unit**
  http://www.anu.edu.au/EMU/index.htm
- **University of Sydney Electron Microscope Unit**
  http://www.usyd.edu.au/su/emu/
- **University of NSW Electron Microscope Unit**
  http://www.anu.edu.au/EMU/index.htm
- **Macquarie Uni Microscopy Unit**
  http://www.bio.mq.edu.au/microscopy/
- **Uni of WA Centre for Microscopy and Microanalysis**
  http://cmm.uwa.edu.au/
- **Qld Uni of Tech Analytical Electron Microscopy Facility**
  http://www.sci.qut.edu.au/aemf/default.htm
- **Adelaide Uni Centre for Electron Microscopy**
  http://www.adelaide.edu.au/CEMMSA/

Robot Blood



Magnetor-heological fluids - or 'MR fluids' are liquids that harden or change shape when they feel a magnetic field. Materials re-searchers at MIT are sug-gesting that they might one day be used to power robots in space.

More info: see http://spaceresearch.nasa.gov/general_info/23aug_MRfluids.html

CSEM

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Research School of Earth Sciences
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Research School of Physical Sciences & Engineering

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