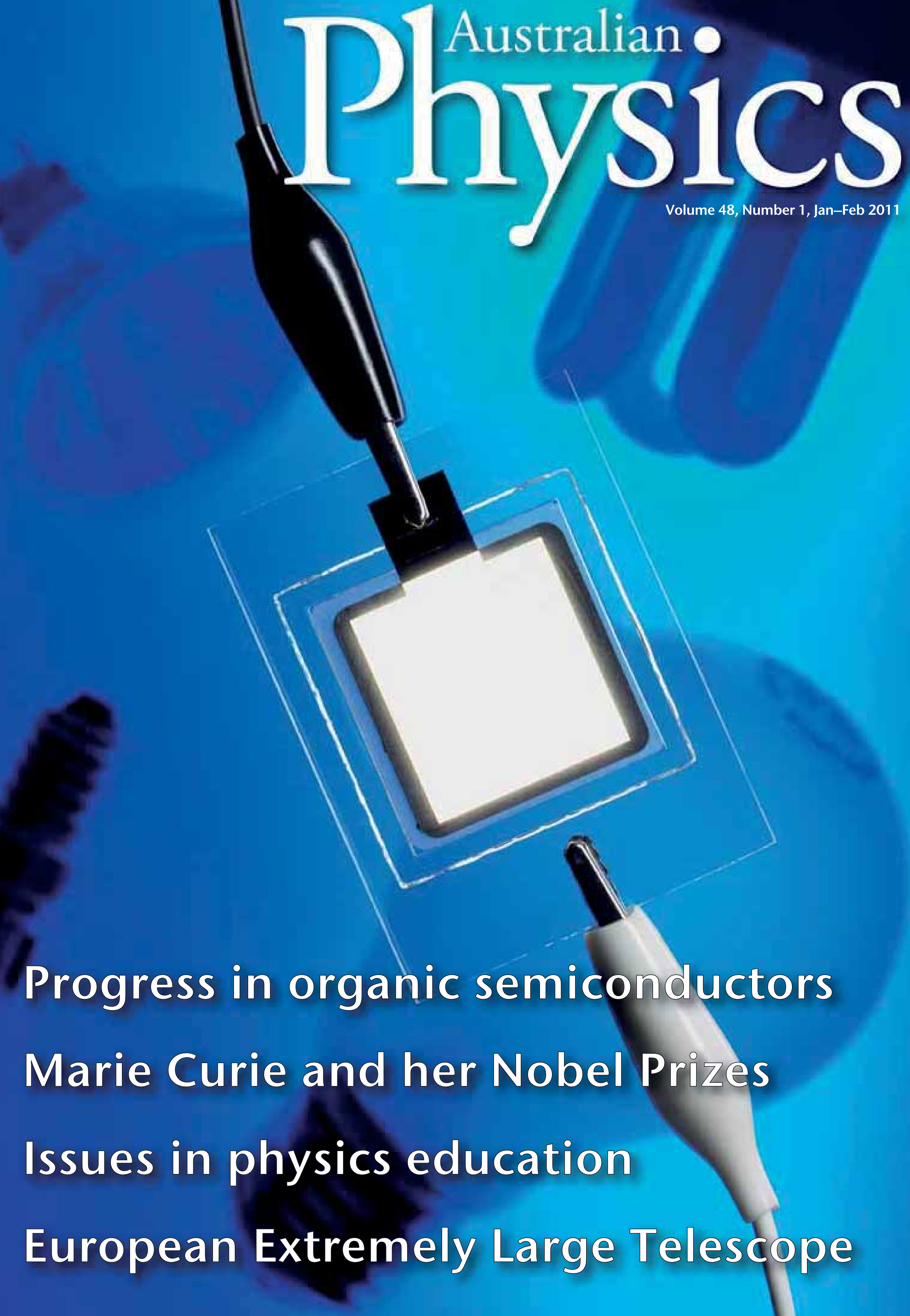

# Australian Physics

Volume 48, Number 1, Jan–Feb 2011

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## Marie Curie and her Nobel Prizes

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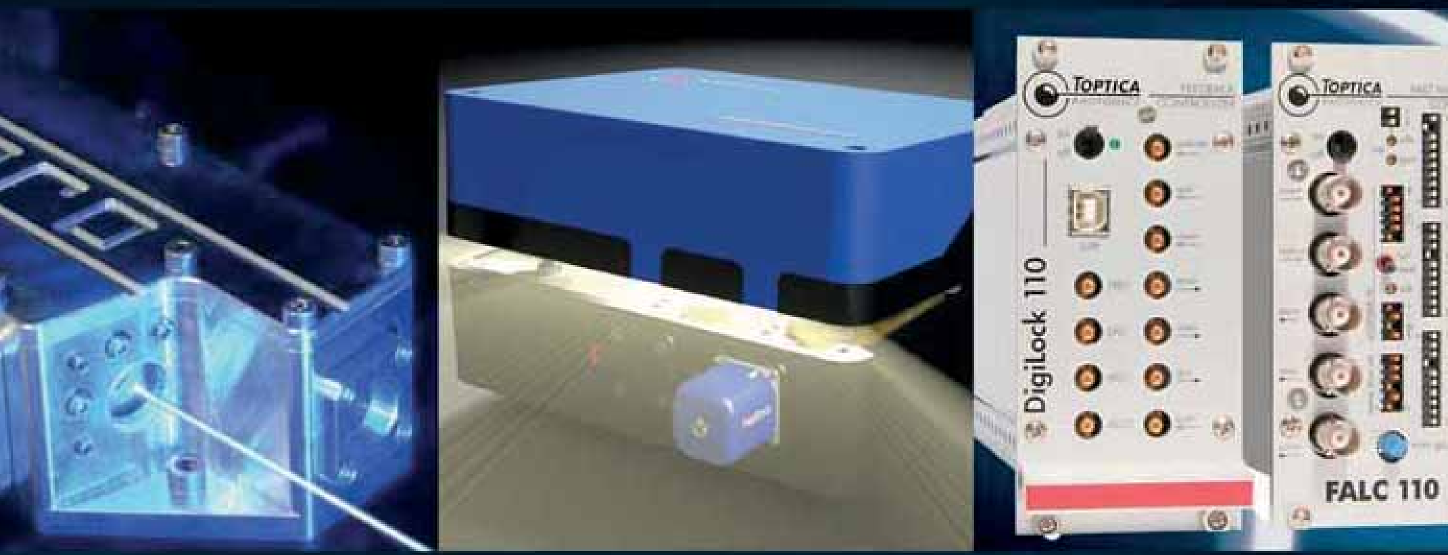


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# 2011 WALTER BOAS MEDAL

## Background and Aims

The Medal was established in 1984 with the aim to promote excellence in research in Physics and to perpetuate the name of Walter Boas (University of Melbourne 1938–47, CSIRO 1947–69). The award is for physics research carried out in the five years prior to the date of the award, as demonstrated by both published papers and unpublished papers prepared for publication, a list of which should accompany the nomination.

Any AIP member may make a nomination or may self-nominate for the award.

## Eligibility/Procedure

Nominees should be members of the AIP and Australian citizens and should have been residents of Australia for at least five of the seven years preceding the closing date for nominations. The Medal shall not be awarded more than once to any person.

The award shall be given for original research making, in the opinion of the examiners, the most important contribution to physics. This will be judged in papers published during the four years immediately preceding the date on which entries for the award close, supported where appropriate by unpublished papers or reports on work carried out during that period.

If a candidate considers that knowledge of work carried out prior to the four-year period is necessary for the correct evaluation of the record of work submitted for the award, reference may be made to the work where published, or an unpublished account of such previous work may be submitted.

## Supporting Information

Candidates for the award should provide the following:

- A brief curriculum vitae covering personal details, academic and professional qualifications, outline professional career history, and honours and distinguished awards. A full CV is not necessary.
- A short account of the research achievements of the candidate (or candidates if there is a joint submission) setting out the achievements on which the application rests and drawing attention to those articles that are important.
- A list of relevant publications, patents and reports by descriptive title and reference related to the achievements on which the application is based. Where heavy reliance is placed upon material not reasonably available, a copy of this material may also be submitted.
- Candidates are invited to provide the names of up to three internationally known referees who have the appropriate expertise to offer a critical appraisal of the candidate's achievements.

## Presentation of the Award

The award is conditional on the recipient delivering a seminar on the subject of the award at a meeting of the Victorian Branch of the AIP in November. The recipient is also expected to provide a manuscript based on the seminar for publication in *Australian Physics* magazine.

# 2011 AWARD FOR OUTSTANDING SERVICE TO PHYSICS IN AUSTRALIA

## Background and Aims

The Australian Institute of Physics has several awards for excellence in some aspect of Physics. They are usually based on the research contributions of the individual or group concerned.

There are many individuals within the AIP who give great amounts of time and effort to the furtherance of Physics as a discipline. While some of these would also be contenders for one or other of the more research oriented awards, others would not. They tend to be quiet achievers, sometimes more devoted to teaching and its development than to research.

The AIP inaugurated an award for Outstanding Service to Physics in Australia in 1996.

## Eligibility/Procedure

The award will be open to members of the AIP. Nominations may be made by a Branch Committee or by three members of the AIP. There will be no more than three awards nationwide in any one year and the Selection Committee, which will be appointed by the Executive, will reserve the right to make no awards in any one year.

The AIP Award for Outstanding Service to Physics will recognise an exceptional contribution on the part of an individual. Nominations should be accompanied by a clear one or two page citation describing the outstanding service given by the nominee.

# TIMELINES

Nominations for both the Boas Medal and the Outstanding Service Award should be sent by **1 August 2011** to:

Dr Olivia Samardzic,
AIP Special Project Officer, 205 Labs, EWRD,
DSTO, PO Box 1500, Edinburgh, SA 5111, or
olivia.samardzic@dsto.defence.gov.au

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## Cover

A prototype white organic light-emitting diode [courtesy: Novaled AG, Dresden]. See the article by Chris McNeill on page 17.




# Australian Physics

**A Publication of the Australian Institute of Physics**

*Promoting the role of physics in research, education, industry and the community.*

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# EDITORIAL

## A year of notable anniversaries

As mentioned in our previous issue, the International Year of Chemistry celebrates the centenary of the award of the Nobel Prize for Chemistry to Marie Curie. The year 1911 was also a notable one for physics. The discovery of superconductivity by Kamerlingh Onnes at the University of Leiden was quickly rewarded by the Nobel Prize for Physics in 1913.

Even more remarkable was the discovery of the atomic nucleus by Ernest Rutherford and colleagues at the University of Manchester. Perhaps equally remarkable was that Rutherford's breakthrough did not lead to a Nobel Prize, even though a little over three decades later it was to irreversibly change world politics like few other discoveries in science.

This year marks a number of other notable anniversaries. It is now fifty years since the first manned spaceflight by Soviet cosmonaut Yuri Gagarin. It was also 1961 when the iconic Parkes Telescope in NSW came into operation, arguably the most successful scientific instrument ever built in Australia. We will be celebrating a number of these milestones in a series of articles in *Australian Physics* scheduled for 2011.

You may have noticed that the magazine has a new look, nothing radical but a number of relatively small but significant changes. We have made the text less dense by going up a point in typesize and widening the margins, so that the text can 'breathe' a little more. Similarly, we will make more use of quality images so that pages are more visually attractive and in line with contemporary magazine standards.

Most importantly, we want to improve not just the presentation, but also the quality of our articles. In the long term we believe this is the best step towards attracting our readers to contribute articles about their latest achievements in Australian physics.

It is a great pleasure to introduce to you our new publisher, Guy Nolch, on page 8.

**Editor's note: The page numbers assigned to Volume 47, Number 4 were incorrect. There was a total of 188 pages published in the six issues comprising Volume 47, not 160 pages as suggested by Volume 47, Number 6.**

# ERA – where to from here?

As a researcher and research manager from outside the university sector I have sat bemused by the Excellence in Research for Australia assessment of university disciplines; in particular, the journal ranking which has been a source of great angst and debate.

There were unresolved problems dealing with papers with large numbers of authors, with research classifications that were at odds with international schemes and with journal rankings that apply to all disciplines covered by a journal even though the journal may be much stronger in one discipline than another. The AIP wrote to the ARC expressing these concerns.

Research managers, whose job it is to enhance research standing and income for their institution, quickly realised that papers should be preferentially published in A* and A journals, even where this was not the best place with respect to the particular discipline concerned. Some set up targets for publishing in these journals and research staff knew that career progression would partially depend on targeting those journals. This was an unintended consequence of the scheme but it is one that should have been obvious to the policy bureaucrats – I find it concerning that it wasn't recognised from the start.

A less recognised consequence of the policy is that it could represent the death knell for some Australian journals. They are invariably B or C rated and often carry material that is 'local' or that does not fit the larger journals publication policy (e.g. publishing datasets or catalogues). It is valuable work that deserves publication and it is appropriate to publish it in Australia, but that may not be possible if the push away from lower ranked journals continues and these niche journals are forced to close.

When I publish my research the first question I ask is "who do I want to read this work?" The answer for any researcher is "the people in my field who will be most influenced by the result" and so they should choose the journal of the highest standing and readership for that particular discipline and sub-discipline. If the topic has a very small research base and a relevant specialist journal, then that is where to publish. All papers in this small field may have 'relatively' low citations simply because of the field size. The specialist journal will naturally be ranked lower than a broader journal or one for a larger field.

I was therefore interested to read Minister Carr's press release on 30 May 2011 where he praised the enormous success of the ERA system and then stated: "The ARC has advised me that consultation has revealed that there is a widespread preference for limited change, to ensure that ERA 2010 and ERA 2012 outcomes can be compared."

A very interesting choice of words. I am sure there was "a widespread preference for limited change", but not so certain about the rest of the sentence.

The release listed some of the changes including:

- The refinement of the journal quality indicator to remove the prescriptive A*, A, B and C ranks
- The introduction of a journal quality profile, showing the most frequently published journals for each unit of evaluation
- Increased capacity to accommodate multi-disciplinary research to allow articles with significant content from a given discipline to be assigned to that discipline, regardless of where it is published…

It remains to be seen what some of these phrases *actually mean* and whether they will represent a scheme that meets the necessary requirements without unintended consequences and without the level of dissatisfaction amongst researchers that has been present to date.

Before closing I would like to make an appeal to all readers. The Physics Decadal Plan needs input from all physics areas and from people at all career levels if it is to be successful. It is your opportunity to have a say in the development of physics for the future. We are all too happy to sit back and criticise what is happening in our field now, but we can't complain in the future if we haven't bothered to make an effort to contribute to the plans for that future. You will have received emails asking for input and I encourage you to take up the challenge and make a submission. If you can't find where to respond to then contact Prof. David Jamieson at d.jamieson@unimelb.edu.au who is managing the plan development for the Academy of Science.

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## Silicon photonic crystals to slow down light

New research in light sources led by the University of Sydney will result in information speeds many times faster and data that are almost impossible to hack. The breakthrough, which uses silicon photonic crystals to slow down light, is a collaboration between the two Centre of Excellence for Ultrahigh Bandwidth Devices for Optical Systems (CUDOS) nodes at the University of Sydney and Macquarie University, along with colleagues at the University of Bristol, the University of St Andrews, and the Ecole Centrale de Lyon.

CUDOS researchers have generated individual pairs of photons in the smallest device ever achieved by slowing down light using silicon photonic crystals. At 100 microns in length the photon device developed by CUDOS is 100 times smaller than the one-centimetre devices used by other groups.

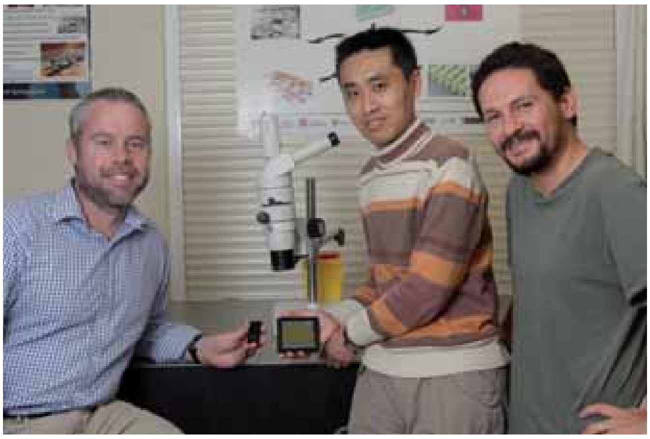
Dr Chunle Xiong at the University of Sydney, a co-author and project leader for the CUDOS program in Quantum Integrated Photonics, says that the small size means that potentially hundreds of these photon devices can be incorporated onto a single chip. This is a key step to building practical quantum technologies that will make communications much more secure and computations much faster.

Xiong notes, “We are able to do this by slowing light through the use of silicon photonic crystals, which means the ultra-short device behaves as a much longer device, so that the photons are generated in only 100 microns.”

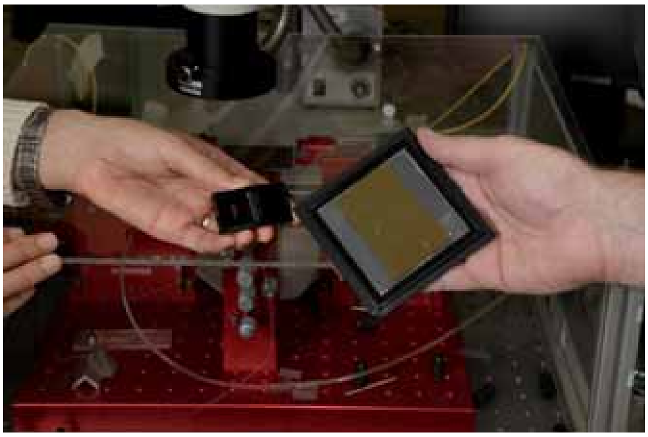
A/Prof Michael Steel from Macquarie University, co-author and CUDOS chief investigator, notes that: “Current systems use classical light to carry information, which hackers can easily tap into and use to their advantage. But you cannot copy the information encoded in quantum states without being noticed by the system. Single photon devices will ensure communication and information systems are secure from hackers, guaranteeing peace of mind for the users.”

This pioneering technology will ensure that the next generation of information systems is secure and faster, according to Professor Ben Eggleton, co-author and director of CUDOS at the University of Sydney. The research was outlined in a paper presented at a conference in Baltimore in early May.

Eggleton says this breakthrough is taking CUDOS ‘Mark II’ into a new and exciting direction. Federal Minister for Innovation, Industry, Science and Research, Senator Kim Carr, officially launched CUDOS II in April.



**Professor Ben Eggleton (left), Dr Chunle Xiong and Dr Christian Grillet [credit: Lee Besford].**



**The smaller CUDOS chip compared to the original-sized chip [credit: Lee Besford].**

## Women in Physics lectureship

The AIP Women in Physics Lectureship for 2011 has been awarded to Dr Tamara Davis from the University of Queensland. Davis specialises in interpreting astrophysical observations in terms of their implications for fundamental physics. In the last five years she has performed cosmological analyses for ESSENCE and the Sloan Digital Sky Survey Supernova Search, and has recently returned to Australia to work with the Wiggle-Z dark energy survey.

In 2009 Davis was awarded both the Louise Webster Prize for early-career research and the L’Oreal Women in Science Fellowship. She has over 30 publications, including two *Nature* papers and five with over 100 citations. She enjoys making science accessible to the public and regularly gives popular talks to the media.

Tamara’s main WIP lecture topic will be ‘Cosmological confusion: Revealing common misconceptions about

**Dr Tamara Davis is the AIP Women in Physics lecturer for 2011.**

the big bang, the expansion of the universe and cosmic horizon'. The WIP Lecture Tour around Australia will include professional, school and public lectures and will commence in September 2011.

## Paper stronger than steel

Physicists at the University of Technology Sydney have reported remarkable results in developing a composite material based on graphite that is as thin as paper and ten times stronger than steel. Based on preliminary research done at the University of Wollongong, the UTS team led by Professor Guoxiu Wang has developed samples of graphene paper (GP), a material with the potential to revolutionise the automotive, aviation, electrical and optical industries.

GP is a material that can be processed, reshaped and reformed from its original raw material state – graphite. The UTS group has successfully milled the raw graphite by purifying and filtering it with chemicals to reshape and reform it into nano-structured configurations which are then processed into sheets as thin as paper. These nano-sheet stacks consist of monolayer hexagonal carbon lattices and are placed in perfectly arranged laminar structures which give them exceptional thermal, electrical and mechanical properties.

Using a synthesised method and heat treatment, the team has produced material with extraordinary bending, rigidity and hardness mechanical properties. Compared

## INTRODUCING… GUY NOLCH

**Guy Nolch is responsible for the new design and layout of *Australian Physics*.**

**Guy is the Publisher and Editor of *Australasian Science* (australasianscience.com.au), which is the only monthly science magazine dedicated to science in Australia and New Zealand.**

**Guy is also Publisher of *Issues* (issues.com.au). Each edition explores a particular scientific topic, with key experts and stakeholders giving their perspectives on issues such as climate change adaptation, population, patenting and food security.**

**Guy also produces *Chemistry in Australia* for the Royal Australian Chemical Institute.**

**Ali Reza Ranjbartoreh at the University of Technology Sydney with a sample of graphene paper [credit: Lisa Aloisio].**

with steel, the GP prepared is six times lighter, five to six times less dense, and twice as hard, with ten times higher tensile strength and 13 times higher bending rigidity.

According to lead researcher Ali Reza Ranjbartoreh: "No one else has used a similar production and heat testing method to find and carry out such exceptional mechanical properties for graphene paper. We are definitely well ahead of other groups. The exceptional mechanical properties of synthesised GP make it a promising material for commercial and engineering applications. Not only is it lighter, stronger, harder and more flexible than steel, it is also a recyclable and sustainable manufactured product that is eco-friendly and cost effective in its use."

Ranjbartoreh points out that the results promise considerable benefits for the use of graphene paper in the automotive and aviation industries, allowing the development of lighter, stronger and cheaper cars and planes that will use less fuel and generate less pollution, as well as being ecologically sustainable.

Large aerospace companies such as Boeing have already started to replace metals with carbon fibres and carbon-based materials. Graphene paper with its extraordinary mechanical properties is likely to be the next material for them to explore. The production of GP from graphite will provide a remarkable amount of added value for the mining, material processing and manufacturing industries in Australia. In the last decade, there has been a rapid increase in the replacement of metals by carbon-based materials. Australia has immense graphite resources making the new material a favourable option to industry as an economic, home-grown and world-class technological advancement for mass production and industrial application. The UTS research 'Advanced mechanical properties of graphene paper' has been published in a recent issue of *Journal of Applied Physics*.

# Science in a New Light

Stuart Woollett

**A pioneer among scientists – female scientists in particular – Marie Curie and her achievements are this year being celebrated as part of the International Year of Chemistry in 2011, being the centenary of her Nobel Prize in Chemistry.**

Marie Curie is linked to my workplace – tenuously but directly nonetheless. In the late 1920s, as Director of the Curie Laboratory of the Radium Institute in Paris, she signed certificates for radium for distribution to foreign countries, including Australia. These samples arrived in Melbourne to be disseminated to medical facilities around the country for their use in radiation therapy.

**"She was the first woman in France to receive a doctorate, the first female professor at the Sorbonne, and was appointed the Director of the Curie Laboratory in the Radium Institute of the Sorbonne on its founding in 1914."**

These certificates were placed into the possession of the Commonwealth Radium Laboratory, established in 1929 as part of the School of Natural Philosophy within the University of Melbourne [1]. The responsibility of this body was to safeguard the radium purchased by the government and to ensure its safe and proper use. Through its many guises this laboratory has become the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

It was radium, as well as polonium, both discovered by Marie and her husband Pierre, and her ongoing studies of radioactivity, that led to her being awarded the Nobel Prize in Chemistry in 1911. This 100th anniversary coincides with the centenary celebration of the inception of International Women's Day, celebrating the economic, political and social achievements of women past, present and future. What better illustration of a woman's dedication, resilience and achievement than that of Marie Curie?

Marie Curie was the first female recipient of the Nobel Prize, which occurred earlier in 1903. It was then that she was awarded the Nobel Prize in Physics along with her husband Pierre, and physicist Henri Becquerel, 'in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel'.

The research leading to this accolade was many years in the making. In the late nineteenth century, following the work of Becquerel, Marie Curie discovered that radiation levels are proportional to the quantity of uranium or thorium, and that this activity is an atomic property of the element. In her Nobel Lecture for Chemistry in 1911, she said:

> 'I was struck by the fact that the activity of uranium and thorium compounds appears to be an atomic property of the element uranium and of the element thorium. Chemical compounds and mixtures containing uranium and thorium are active in direct proportion to the amount of these metals contained in them. The activity is not destroyed by either physical changes of state or chemical transformations.'

The idea of the spontaneous emission of rays was first observed in the experiments of Henri Becquerel.

Marie Curie took the further step of showing that the energy came from the atom itself. She then proceeded to analyse numerous and varied samples for their radioactivity. Marie Curie's moment of revelation came when she discovered that the radioactivity of minerals such as pitchblende was stronger than for the oxides of uranium and thorium. She deduced that these minerals must contain other substances that are more radioactive, i.e. a new element!

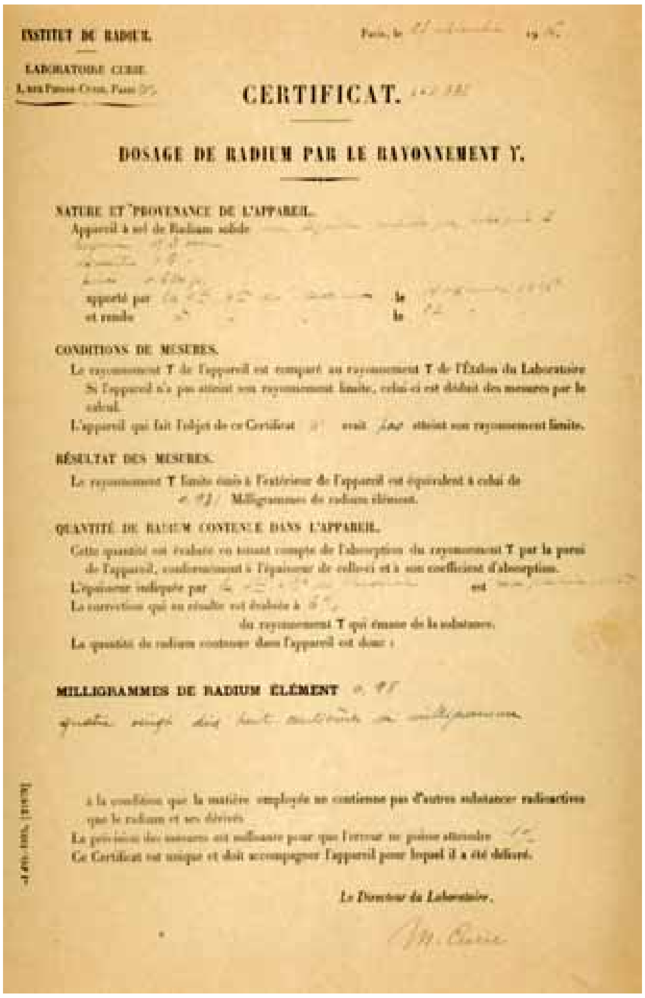
Pierre's excitement at the prospect of the discovery of a new element led him to abandon his work and partner his wife on her quest. Up until then he had provided his thoughts and advice; now he joined in her efforts. In the presentation speech by the President of the Swedish Academy of Sciences [2], H. R. Törnebladh noted that Marie and Pierre Curie had found:

> '… that the radioactive properties of the mineral pitchblende were more marked than those of uranium, came to the conclusion that pitchblende must contain one or more new radioactive substances. By breaking up pitchblende into its chemical components and examining… the radioactivity of the products that were obtained, they at last managed by means of a series of solutions and precipitates to isolate the materials that were distinguished by radioactivity of extraordinary intensity'.

In 1898, with the assistance of chemist Gustave Bémont, the Curies had performed chemical separations and purification on pitchblende, analysing the resultant samples for their radioactivity. Marie had become a pioneer of radiochemistry. From these experiments, the elements polonium (named after her native country Poland) and radium (named from the Latin word *radius*, meaning 'ray') were discovered.

The phenomenon of radioactive transformation had been discovered. Some of the scientific community were sceptical of the Curies' discovery and required further evidence: a demonstrable amount of the element and a determination of its atomic weight. Given the minute quantities of radium and polonium in pitchblende, this was to be an onerous task.

For the next four years, as well as their part-time teaching, the Curies worked on the chemical separation and purification of radium and polonium from tons of pitchblende residue. In her Nobel Lecture in 1911, Marie went on to say: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et rendu … le …

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L'appareil qui fait l'objet de ce Certificat … avait … atteint son rayonnement limite.

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La correction qui en résulte est évaluée à … du rayonnement γ qui émane de la substance.

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Le Directeur du Laboratoire,

M. Curie

**This certificate of radium assay by gamma radiation was signed by Marie Curie in 1926.**

> 'The first treatment consists in extracting the radiferous barium and the bismuth containing the polonium… About 10 to 20 kg crude barium sulphate containing radium are extracted from one ton of residue. The activity of these sulphates is even then 30 to 60 times greater than that of uranium. These sulphates are purified and converted to chlorides. In the mixture of barium and radium chlorides the radium is present only in the proportion of about 3 parts per 100,000… To separate the radium from the barium I have used a method of fractional crystallisation of the chloride (the bromide can also be used). The radium salt, less soluble than the barium salt, becomes concentrated in the crystals… The progress of the fractionation is monitored by activity measurements.'

Marie was able to prepare a decigram of almost pure radium chloride and make a determination of radium's atomic weight.

One evening the couple returned to their laboratory and without lighting the lamps marvelled at the spon-


**Periodic table with $^{84}$Po discovered by Pierre and Marie Curie. The element was named polonium in honour of the country of birth of Marie Curie (nee Sklodowska) [credit: iStockphoto/David Freund].**

taneously luminous radium samples casting out bluish light [3]. And during a party celebrating Marie's submission of her doctoral thesis, Pierre held aloft a sample of radium. In the illuminated darkness, their friends stared in wonder.

The Curies were particularly interested in the therapeutic properties of radium. It was found to be useful in the treatment of cancer, originally called 'Curie-therapy'. The radium industry was born.

**"For all the contention of what work is attributable to Marie and what to her husband, it is evident that after Pierre's death Marie was quite capable of continuing the research at which they had toiled for many years."**

The much shorter half-life and extremely small concentration of polonium in pitchblende meant that purification in sufficient quantity was extremely difficult. It wasn't until years later that she and André Debierne extracted a few milligrams of the substance.

In 1911 Marie received the Nobel Prize in Chemistry in recognition of her work in radioactivity, especially the isolation and characterisation of new elements. The discovery of polonium and of radium triggered a series of research works, leading to the discovery of other radioactive elements associated with the decay of uranium and thorium, for example actinium and protactinium.

Marie Curie was the first person to win two Nobel Prizes and is so far the only woman to have done so and the only person to win Nobel Prizes in two scientific disciplines. She was also awarded the Davy Medal of the Royal Society in 1903. And she was awarded the Gegner Prize by the French Academy of Sciences; however, because she was a woman it was left to her husband to inform her of her achievement.

She was the first woman in France to receive a doctorate, the first female professor at the Sorbonne, and was appointed the Director of the Curie Laboratory in the Radium Institute of the Sorbonne on its founding in 1914. She is also the only woman accorded the honour of being laid to rest in the Panthéon on her own merit (this occurred much later, in 1995).

In 1921, on behalf of the women of America, President Harding gifted her institute one gram of radium – at that time, radium was one of the most expensive substances in the world.

Marie had two daughters, Irène and Eve. Irène, along with her husband Frédéric Joliot, was awarded the Nobel Prize in Chemistry in 1935 for 'their synthesis of new radioactive elements'. In 1934 the pair had discovered artificial radioactivity, i.e. new radioactive elements produced by the bombardment of non-radioactive elements with alpha-particles or neutrons.

Marie was devoted to her children to the extent that, according to Denis Brian in his biography [4], her husband once berated her after she spent some time with Irène: 'You never think of anything but that child!'

Marie raised her children as a single parent from 1906. With her daughters aged eight and one, she was widowed by the death of Pierre, who was crushed under the weight of a horse-drawn wagon. Although

**Pierre and Marie Curie about the time they and Henri Becquerel were awarded the 1903 Nobel Prize for Physics [credit: AIP Emilio Segre Visual Archives].**

there was some assertion that radiation sickness might have affected his concentration on that fateful day, radiation is not what killed Pierre Curie. He was, however, ill for extended periods following their radium extraction work. During 1905 he was taking strychnine, at the time a treatment for neurasthenia. He later realised that this was not what was ailing him. Marie too became ill due to her work. In 1903 she was too sick to travel to Sweden to receive the Nobel Prize.

Marie Curie died in 1934, at the age of 66, from aplastic anaemia, a blood disease that can result from exposure to radiation. Given her close and consistent handling of radioactive materials, her length of life – beyond life expectancies at the time – could be considered surprising.

For all the contention of what work is attributable to Marie and what to her husband, it is evident that after Pierre's death Marie was quite capable of continuing the research at which they had toiled for many years.

As the President of the Royal Swedish Academy of Sciences noted on the award of the Nobel Prize in 1903 [2]:

> 'The great success of Professor and Madame Curie is the best illustration of the old proverb, *coninucta valent*, union is strength. This makes us look at God's word in an entirely new light: 'It is not good that the man should be alone; I will make him an help meet for him.'

A new light indeed.

## References


[1] J. F. Richardson, 'The Australian Radiation Laboratory: A Concise History 1929–1979' (AGPS, Canberra, 1981).

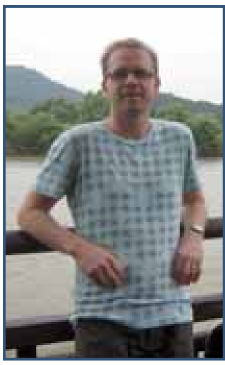
[2] Presentation speech by H. R. Törnebladh, President of the Royal Swedish Academy of Sciences, 10 December 1903.

[3] Eve Curie, 'Madame Curie: The Biography by Her Daughter' (Mercury Books, London, 1968).

[4] Denis Brian, 'The Curies: A Biography of the Most Controversial Family in Science' (John Wiley & Sons, New Jersey, 2005).



**A similar version of this article appeared earlier in *Chemistry in Australia*, April 2011, 18–21.**

## ABOUT THE AUTHOR


**Stuart Woollett is a Research Scientist at the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). He has been at what was formerly the Australian Radiation Laboratory since 1997 and has worked in a variety of areas. These include the clean-up of the Maralinga atomic tests sites; monitoring radon concentrations in cave systems; and undertaking health impact assessments of sewage workers, Defence Force veterans and Australian citizens in emergency situations overseas. Currently Stuart is involved in developing national and international guidance on assessing the safety of radioactive waste management facilities over their lifecycle.**

AIP EDUCATION MEDAL FOR 2010

# Physics Education: Resources and Recovery

Joe Wolfe

**With the award of the AIP Education Medal, which I received with delight, came the request to speak about education at the AIP Congress in Melbourne in December 2010 and to write an article for *Australian Physics* magazine. I thought that I could usefully talk and write about two topics in education. One is a learning and teaching project in introductory physics, while the other is the struggle over physics in high schools, a struggle that physicists may be losing.**

## A multi-level, multimedia resource

Physclips is a multi-level, multimedia introduction to physics, covering the levels from late high school to first-year university. Thus far, it covers mechanics, waves and sound, and provides resources in other areas. It is made by George Hatsidimitris, John Smith and myself, and supported by the Australian Learning and Teaching Council and the School of Physics at UNSW.

For teachers, Physclips is a collection of film-clips, animations, sound files and images that may be downloaded for use in lessons, or as reference material. For students, we intend it to be a flexible resource for learning, revision or reference.

Physclips combines film clips of experiments with animations, diagrams and explanations in both voice-over and text. Often, film-clips are integrated with material such as vectors, plots and histograms animated to represent time-varying quantities in the clips.

Each chapter has a brief multimedia overview, typically ten minutes, which branches via links to extensive supporting material giving broader and deeper discussion. In the recent chapters, laboratory sections are included to provide hands-on activities utilising a computer plus some common, inexpensive components.

Physclips attracts over 2000 individual visitors per day. Its teaching elements are incorporated into lessons at MIT and Harvard, as well as in schools in outback Australia, Africa and elsewhere (see [1]).

## Putting physics into the high school physics syllabus – Can we regain some of the lost ground?

Like many others, I read the draft national curriculum for physics and thought that, if interpreted and taught with appropriate understanding and emphasis, it *could* be exciting, useful and educational. Unfortunately, that seems unlikely to happen. The problem is that, as it is currently written, it could also be interpreted as resembling the subject known as Physics in the NSW high school system, introduced several years ago [2]. This would be a national tragedy. Nevertheless, powerful stakeholders will certainly push it in this direction.

The original draft national syllabus must therefore be rewritten in a way that makes it clear it is a physics curriculum. Together with colleagues Elizabeth Angstmann and Richard Newbury (head of physics at UNSW), I wrote our school's response to the national curriculum (see [3]).

Briefly, our suggestions are these:

- The quantitative and predictive nature of physics and the importance of problem solving must be stressed, and it must be made clear that description, history and social studies are only minor elements. The best way of doing this is the usual way: state the important laws and principles in terms of equations. Including more than a small section without equations misleads students about the nature of physics.

- The national curriculum should also include a subject called General Science (and perhaps even General Physics). This subject would cater to students who wanted to learn *about* science but who did not wish or did not have the abilities to *do* science. Along the lines of the current Senior Science course in NSW (and much of the HSC Physics course in NSW), General Science could cater for students who wish to continue learning about science and the historical and sociological aspects of the subject, without the rigour required to study physics or chemistry. It would be understood that this subject would not, on its own, be a suitable introduction to further study in science, engineering, etc. Such a subject would free Senior Physics from the pressure to appeal to students who do not like physics and/or have no talent for it.
- The curriculum should make it clear that the most important component of the course is solving physical problems, mainly quantitative ones. Quantitative problem solving skills are not only of great importance to those who continue to university study in science and engineering, but to those seeking work in a wide variety of fields.
- We are concerned about the prominence given to history and sociology. Students should learn how to *do* physics, rather than just learn *about* it. We are not opposed to the humanities. However, just as we do not expect that physics be taught in humanities subjects, we oppose giving more than a small fraction of assessment in physics to humanities subjects.

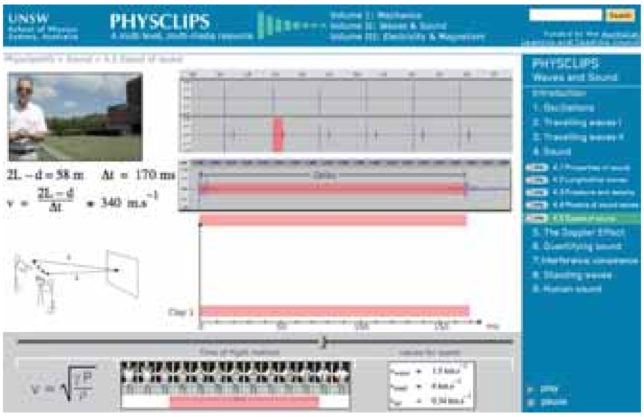


**Fig. 1. A Physclips screen grab comes from a film-clip of measurements of the speed of sound using the time-of-flight method. In the upper panel, the sound of clapping hands travels to the microphone both directly and via an echo from a wall 30 m away. The icon below the scrollbar shows an alternative method using a distant source.**

**Fig. 2. This screen grab shows a section that discusses similarities in different problems. The ballistic pendulum (icons at lower left) involves an inelastic collision (momentum approximately conserved) and a pendulum swing (mechanical energy approximately conserved). In the circus stunt of the main picture, an inelastic collision of hammer and brick is followed by a (happily elastic) deformation of the presenter's chest.**

## Why is there so little physics in current 'high school physics'?

Strong pressures from powerful interest groups have led to this unfortunate result:

- *Teachers* Many high school physics teachers are frustrated by the new syllabi – but not all. In high schools, physics is often taught by teachers who have not been trained in physics. Very many more science teachers have training in biology than in physics, so there are not enough physics teachers to go around. Teachers who are not trained in physics may not always be unhappy to see the physics content reduced.
- *Students* There will always be students who love physics. And there will always be those who hate it. For some students, history and sociology are easier than physics. Such students are not disappointed when the physics is displaced from the physics curriculum.
- *Parents* In a real physics exam, students who spend long hours memorising facts do not necessarily do well. This can seem unfair to some hardworking students and their parents. Perhaps the NSW curriculum seems attractive to some because hard (but mindless) rote learning can be rewarded by good exam scores.
- *Educational theorists* Many education specialists are trained in the humanities. To such specialists, teaching the history of a subject rather than teaching the subject itself does not seem crazy.

Pressure of this sort from these groups will continue. The curriculum should therefore include the specification that history and sociology are to be only a very minor part of study.

## What and whom is senior high school physics 'for'?

Senior high school physics must necessarily serve a range of users. Many will never study physics again, others will study disciplines in which some physics ability and knowledge is useful, and some will go into engineering, technology or physical sciences.

This last group is a minority, but its needs are disproportionately important, because of the importance of science, technology and engineering to Australia's future. These students should have the opportunity, while in high school, to discover that they are good at physics.

> "Physclips attracts over 2000 individual visitors per day. Its teaching elements are incorporated into lessons at MIT and Harvard, as well as in schools in outback Australia, Africa and elsewhere."

For those who will rarely or never use physics after high school, it is important that those taking the subject Physics to find out what physics is like should actually find out what physics is like. The history, sociology and qualitative descriptions are available in any number of popular books, often written by very good physicists for this purpose. These can be learned outside school.

For those who have a real distaste for analytical thinking, quantitative analysis and modelling real world problems, senior high school physics will be unattractive – or at least should be! It is not a compulsory subject. Those attracted to history already have the opportunity to study it. Those attracted to physics should have the opportunity to study it.

Therefore, for all users, it is important that the quantitative nature of the subject, only hinted at in the draft curriculum document, should be made strongly explicit.

## What can we do?

Don't do nothing – our discipline needs you, and you can influence those who will make the decisions. According to the Australian Curriculum, Assessment and Reporting Authority (ACARA), further consultation is planned for 2011 (see e.g. [4]). The AIP's education convenor is Dr Mark Butler, a previous recipient of the Prime Minister's Prize for Excellence in Teaching. Mark is one of the consultants for the Physics Curriculum and can be contacted at drbutler@ozemail.com.au. The AIP Executive can be contacted at executive@aip.org.au.

## Notes

[1] Physclips can be found at www.animations.physics.unsw.edu.au.

[2] Over several years, there has been a reaction against the NSW syllabus and recent exams have had less Humanities content. This is an important improvement and those responsible deserve our congratulations.

[3] Our response to the National Curriculum is available as a PDF at www.phys.unsw.edu.au/~jw/NationalCurriculumResponse.pdf.

[4] See the websites at www.acara.edu.au and www.australiancurriculum.edu.au.


## ABOUT THE AUTHOR

Joe Wolfe is a professor of physics in the School of Physics at the University of New South Wales. He has also held positions at Cornell University, CSIRO, the ANU and the Ecole Normale Supérieure. His early research was in cellular biophysics. Currently, his lab investigates the acoustics of the voice, the ear and musical instruments, publishing in high profile journals including *Nature* and *Science*. Wolfe has won several international and national awards for research and also for teaching. Outside the lab, he is a composer of orchestral and chamber music. His trumpet concerto will have its fifth performance this year, but he is more notorious for a suite of orchestral versions of the rock classic 'Stairway to Heaven', with movements in the styles of Schubert, Beethoven and several others. Joe can be contacted at j.wolfe@unsw.edu.au.

# ORGANIC SEMICONDUCTOR DEVICES: *Physics and Applications*

Chris McNeill

**Organic semiconductors have a surprisingly rich history with the optoelectronic properties of organic crystals studied in the 1960s and the conducting polymers developed in the 1970s. However, it has only been recently that improved material quality and improved processing methods have allowed the field to dramatically progress.**

Organic semiconductors are comprised of both conjugated polymers and so-called small molecules – see Fig. 1a for examples. The optoelectronic properties of these materials derive from the network of alternating single and double bonds. A key attraction of organic semiconductors is their ability to be solution-processed, allowing for low-temperature, high-throughput deposition. Solubility is imparted by aliphatic side chains that can also be used to tune electronic properties and molecular packing. Small molecule semiconductors can also be deposited by vacuum sublimation that may still be commercially viable for some applications.

At present, technologies based on organic light-emitting diodes (OLEDS), organic field-effect transistors (OFETs) and organic photovoltaics (OPVs) are in various stages of commercialisation. Here I will give a brief introduction to the physics of organic semiconductors and present some highlights from the development of OLED, OFET and OPV technologies.

## Basic organic semiconductor device physics

The overlapping of the $\pi$-orbitals of $sp^2$ hybridised carbon atoms in a benzene ring lead to the formation of bonding and anti-bonding orbitals. By linking benzene rings together in a similar fashion to forming a daisy chain, there is increased opportunity for charge delocalisation along the chain resulting in bands of bonding and anti-bonding orbitals. These bands of orbitals are analogous to the valence and conduction bands with a 'band-gap' of around 1.5 to 3 eV, depending on the material. For an infinite chain-extended conjugated polymer in the ground state, the highest occupied molecular orbital (HOMO) is significantly delocalised along the chain. An additional charge added to the system, however, lowers its energy

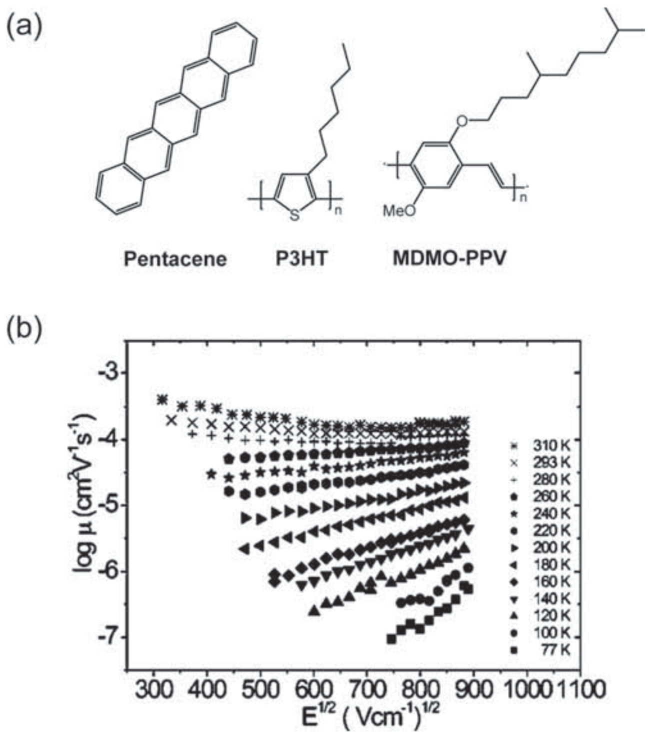



**Fig. 1. (a) Examples of organic semiconductors: the small molecule pentacene and the conjugated polymers P3HT and MDMO-PPV. (b) Electric-field dependence of the charge carrier drift mobility of the polymer P3HT at various temperatures measured by the time-of-flight method (reproduced with permission: Mozer *et al.* [1], © 2005 American Physical Society).**

by inducing a localised deformation of the molecular structure, leading to the formation of a self-localised quasiparticle known as a polaron. Polarons are also known in inorganic physics, however the stronger electron–phonon coupling in carbon-based semiconductors make polaronic effects more significant.

Polaronic effects, however, are swamped by effects due to disorder in the charge transport properties of organic semiconductors. Disorder originates from structural and chemical defects that lead to a distribution of conjugation lengths and site energies. Fig. 1b presents the log of mobility versus the square-root of electric field as a function of temperature for the conjugated polymer poly(3-hexylthiophene) (P3HT). Two features are apparent: charge transport is thermally activated with a complex electric-field dependence. This behaviour can be explained empirically in terms of disorder models with the Poole–Frenkel type dependence ($\log\mu \propto E^{1/2}$) at low temperatures understood in terms of energetic disorder, while the positive electric field dependence emerging at higher temperatures is understood in terms of spatial disorder. Sadly, the temperature and electric field dependence of organic semiconductors varies from material to material, with different charge transport models appearing more appropriate in different circumstances. A comprehensive understanding of charge transport in organic semiconductors in general is still lacking, with dynamic disorder (arising from the vibration of molecules) also thought to potentially play an important part.

## Organic light-emitting diodes

At its simplest an OLED consists of a layer of organic semiconductor sandwiched between two electrodes. One electrode needs to be semi-transparent, and the device operates through the injection of electrons at one electrode and holes at the other with their recombination in the bulk of the semiconductor producing light. High workfunction electrodes are generally required to facilitate hole injection into the HOMO, while low workfunction electrodes facilitate electron injection into the lowest unoccupied molecular orbital (LUMO). In order to optimise injection further, complicated multi-layer structures employing various hole and electron transport/blocking layers are also used – see Fig. 2a.

When an electron and hole meet in an organic semiconductor they form an exciton, a bound electron–hole pair with high binding energy (~0.4 eV) that derives from the low dielectric constant ($\varepsilon_r$ ~ 3–4) and strong electron–phonon coupling. The low dielectric constant also assists the electron–hole capture process due to poor charge screening. By spin statistics, one would expect three-quarters of all excitons formed to be triplets and one-quarter to be singlets, limiting the maximum internal quantum efficiency of OLEDs to 25% (since triplet states are generally non-emissive in conjugated organic compounds). However, it has been found that for conjugated polymers the process of exciton formation does depend on the final spin state, with singlet formation highly favoured over triplet formation. Another way around the triplet-limiting problem is the use of organic phosphorescent triplet emitters that enable up to 100% internal quantum efficiencies. These small molecule phosphors are often used as dopants within an organic semiconductor matrix separating the roles of charge transport and emission.

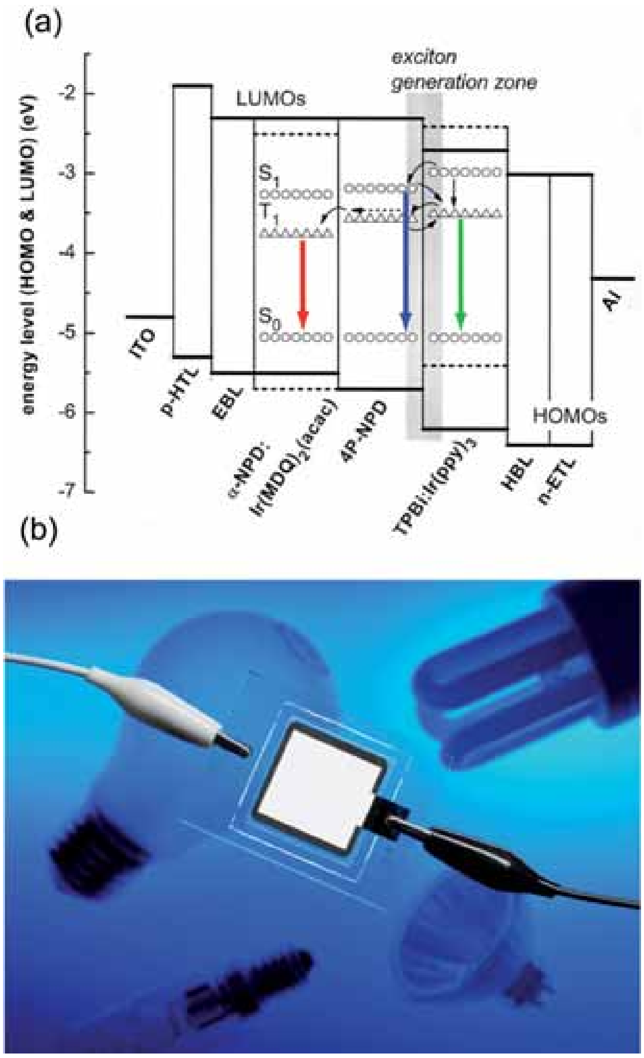



Fig. 2. (a) Energy level diagram of an efficient white-light OLED employing fluorescent and phosphorescent emitters arranged to optimise exciton harvesting. The singlet $S_1$, triplet $T_1$ and ground state $S_0$ of the emitting materials are shown (with permission: Schwartz *et al.* [2], © Wiley-VCH Verlag). (b) A prototype white OLED [courtesy: Novaled].

OLEDs were the first organic semiconductor technology to be commercialised, with a number of commercial products already released. One major market is displays, although OLED flat-screen displays have met tough competition from existing technologies despite possessing superior viewing angles and contrast ratios. Another major potential application is for solid-state lighting. Here the combination of green, red and blue emitters in the one device enables white-light emission. OLEDs are attractive for lighting applications owing to their large-area – see Fig. 2b. This feature provides the opportunity for diffuse lighting and seamless architectural integration.

A recent development has been the demonstration of white-light OLEDs with fluorescent tube efficiency. The realisation of this efficiency relies on a tuning of both the electronic and optical properties of the system. Careful management of the singlet–triplet levels of the emitting species with respect to the transport materials is required to keep the operating voltage low and maintain balanced emission. In addition to optimising the processes of charge injection and recombination, a careful design of the multilayer structure is also required to ensure efficient out-coupling of light from the cavity and to minimise plasmonic losses in the electrodes. This is achieved by using thick electron-transporting layers between the top metal electrode and emissive layers, the use of patterned glass substrates with high refractive index, and half-spheres. In this way luminescent efficiencies of 100 lm/W have been demonstrated. A number of challenges still remain, in particular lifetime issues associated with the blue emitter and further cost reduction.

## Organic field-effect transistors

Transistors are one of the basic circuit components that underpin the operation of all electronic circuits. While inorganic transistors are impressive in terms of their size and speed, there is an opportunity for novel applications based on low-cost flexible transistors. The highest mobilities demonstrated by organic semiconductors are ~40 $cm^2/Vs$ for rubrene single crystals, approaching the best polycrystalline silicon devices. In real-world applications, solution-processed polycrystalline organic semiconductor thin films will most likely be used that exhibit mobilities up to 10 $cm^2/Vs$, comparable with amorphous silicon. Organic transistors are not likely to compete with inorganic transistors on speed and performance, however they offer the opportunity for creating arbitrary, large-area circuits on flexible lightweight plastic substrates. Such a technology has the potential for enabling flexible displays and the widespread application of radio-frequency identification tags.

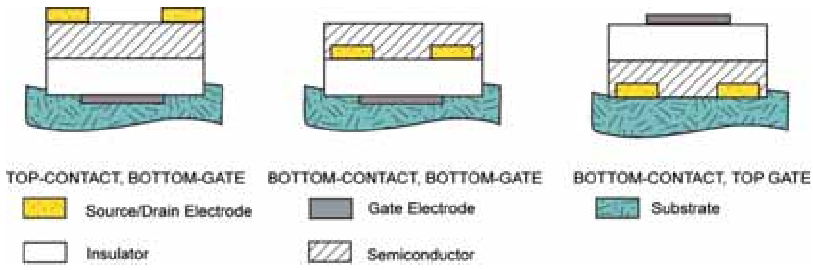



**Fig. 3. Schematic showing the three main OFET geometries.**

The structure of three common OFETs is presented in Fig. 3. In all cases the active semiconducting layer is deposited as a neat, un-doped layer with charge flow through the channel relying on injection of charge from the contacts. Due to the low intrinsic conductivity of organic semiconductors, with no gate voltage applied very little current flows. With the application of a gate voltage, charge is injected into the channel and accumulates at the dielectric/semiconductor interface. Above a certain threshold gate voltage, a potential difference applied between the source and drain electrodes results in current. Varying the gate voltage modulates the charge density in the channel and hence modulates the source–drain current.

While glass or plastic can be used as the substrate, doped silicon substrates coated with a $SiO_2$ dielectric layer have been a convenient choice for bottom-gate transistors, with the doped silicon substrate serving as the gate at the $SiO_2$ film as the dielectric. However, electron trapping at the organic/$SiO_2$ interface (due to surface hydroxyl groups) detrimentally affects operation under electron accumulation. This surface trapping of electrons led to the (erroneous) idea that many organic semiconductors only transport holes and that 'special' organic semiconductors are required for n-channel operation. This led (confusingly) to the classification of organic semiconductors as either 'n-type' or 'p-type', despite the fact that organic semiconductors as used in OFETs are not doped. It has since been shown that through surface passivation of $SiO_2$, or through the use of non-polar polymer gate dielectrics, that many 'p-type' organic semiconductors also transport electrons sufficiently well. Through the use of graphene oxide electrodes, even the quintessential 'n-type' semiconductor PCBM (a $C_{60}$

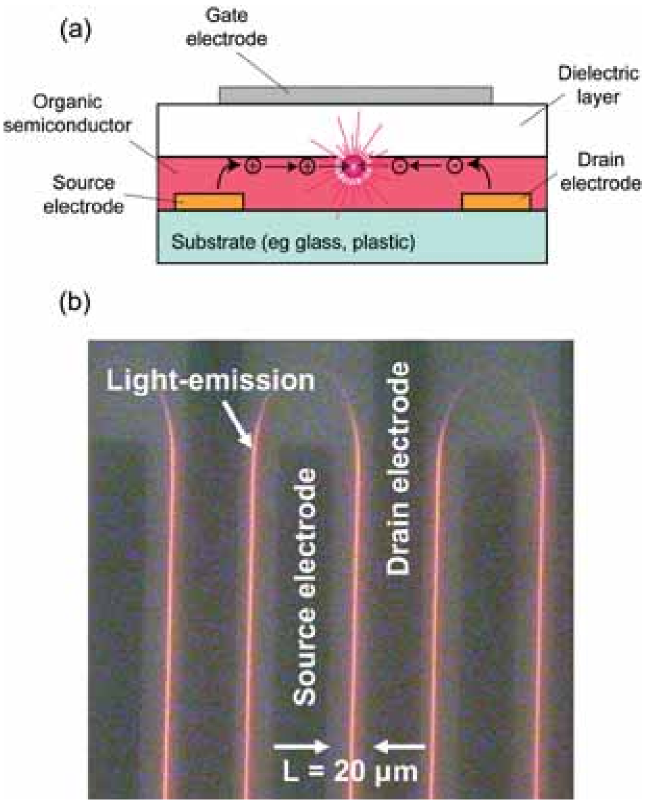



**Fig. 4. (a) Schematic showing the operation of an LFET. (b) The mid-channel recombination pattern of a LFET with inter-digitated source–drain electrodes (with permission: McNeill et al. [3], © 2007 American Institute of Physics).**

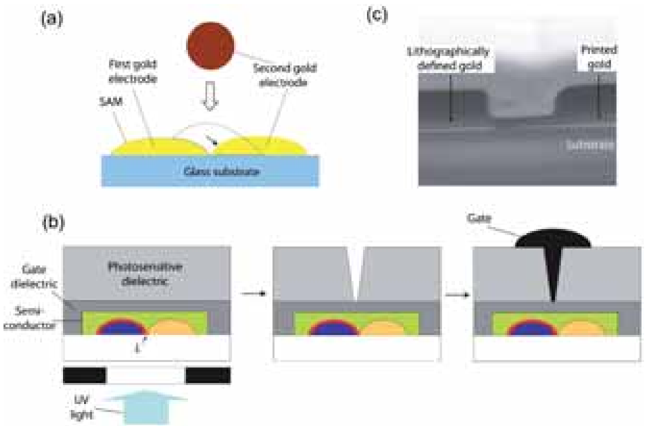



**Fig. 5. (a) Schematic depicting the self-aligned inkjet printing of source–drain electrodes with sub-micron channel length. (b) Minimising parasitic capacitance by using the source–drain electrodes to pattern a thick photosensitive dielectric layer. (c) Electron micrograph of the device (with permission: Noh *et al.* [4], © 2007 Macmillan Publishers).**

derivative, see below) has been shown to be able transport both electrons and holes. However, this terminology still persists to this day and is so firmly entrenched that it is unlikely to be corrected.

A brilliant demonstration of the ability of organic semiconductors to transport both electrons and holes is the light-emitting field effect transistor (LFET). Through the use of different materials for the source and drain electrodes (or through the use of an electrode material with similar injection barrier for electrons and holes), it is possible to simultaneously inject electrons and holes with a gate voltage midway between the source–drain voltage (see Fig. 4a). Under ambipolar operation the charges meet and recombine in the middle of the channel. This recombination zone can be visualised through the use of highly luminescent organic semiconductors – see Fig. 4b – and can be swept across the channel by varying the gate voltage. Though it is uncertain whether the LFET will be useful for any application (the separate use of an OFET paired with an OLED is more efficient), it is a cute demonstration and has allowed for further investigation of the physics of charge recombination.

As the speed of a transistor is related to the channel length, it may seem that high-performance and high throughput solution processing methods are incompatible. An example of how they can be combined is depicted schematically in Fig. 5a. Silver or gold nanoparticle inks are used to print the source–drain electrodes. Due to the limited spatial control of ink-jet printing, the following self-aligned printing process was developed. After printing and drying, the surface energy of the first drop is modified. When the second drop is printed on top of the first drop it is repelled from the surface of the first drop reproducibly leaving a gap of a few hundred nanometres, with the organic semiconductor layer the deposited on top. Thus submicron channel lengths can be achieved without the need for submicron printing resolution.

Another problem limiting the performance of OFETs is the parasitic capacitance originating from overlap of the gate electrode with the source–drain electrodes. A smart way around this without having to directly pattern the gate electrode is by using the printed source–drain electrodes as a mask to pattern a thick photosensitive dielectric that is used in conjunction with an ultra-thin date dielectric – see Fig. 5b. This process allows the gate electrode to be printed while keeping the parasitic capacitance low. In this way printed transistors that are capable of operating over 1 MHz (suitable for low-frequency RFID) have been fabricated.

## Organic photovoltaics

The reason why solar cells are not more widely exploited is simply an issue of cost. Polymer solar cells offer the potential for low-cost manufacture through low-temperature, high-throughput reel-to-reel printing. A number of companies are commercialising this technology, but overall efficiencies are still too low and the promise of the low

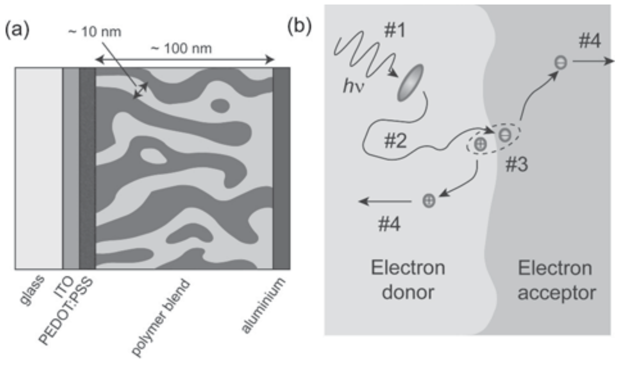



**Fig. 6. (a) Schematic showing the structure of a bulk-heterojunction organic solar cell. (b) Operating mechanisms of an organic solar cell showing: (1) light absorption; (2) exciton diffusion; (3) charge transfer and charge separation; and (4) charge collection (with permission: McNeill and Greenham [5], © Wiley-VCH Verlag).**

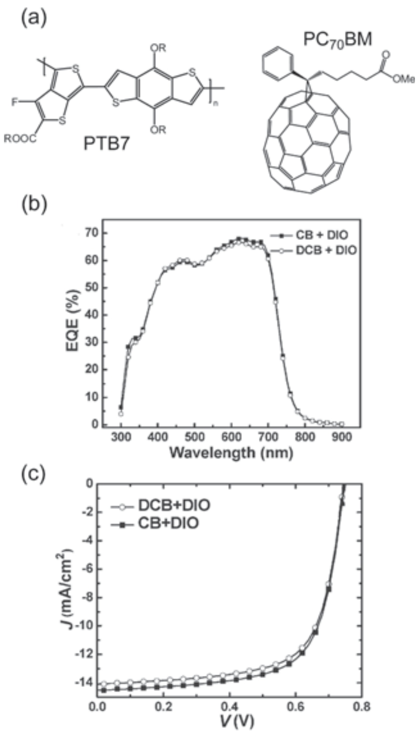



**Fig. 7. (a) Chemical structures of PTB7 and $PC_{70}BM$ (R = 2-ethylhexyl). (b) External quantum efficiency (EQE) spectrum of PTB7:$PC_{70}BM$ blend solar cells. (c) Current–voltage characteristics of PTB7:$PC_{70}BM$ cells (with permission: Liang *et al.* [6], © Wiley-VCH Verlag).**

cost of manufacture still to be fully realised. The schematic structure of an organic solar cell is depicted in Fig. 6a. Similar to OLEDs, organic solar cells have a sandwich-style architecture with ITO typically used as the semi-transparent electrode. An interfacial layer of the conducting polymer PEDOT:PSS is generally used between the ITO electrode and the active layer, with a top metal electrode such as aluminium completing the cell.

The operating mechanisms of an organic solar cell are represented in Fig. 6b. Due to the high exciton binding energy, free charge carriers are not the direct product of excitation. Instead tightly bound excitons are produced that need to diffuse to an interface between materials of differing electron affinity in order to dissociate via electron (or hole) transfer. Since excitons only diffuse around 10 nm, with the optical absorption length around 200 nm, a blended or 'bulk heterojunction' architecture is used to balance these competing requirements. The donor and acceptor materials are deposited from a blend solution and nanoscale interpenetrating networks formed through the phase separation of the two components. Domain sizes of order 10 nm ensure all excitons reach an interface, while interpenetrating networks ensure charges reach their respective electrode. Of course, control of nanostructure through solution processing is tricky, but it has been shown to work reasonably well for some systems.

After exciton dissociation, the interfacial electron–hole pair is not necessarily free with a binding energy of ~100 meV or more. How charges separate from the donor–acceptor interface is currently a topic of hot debate. There is evidence that this process is electric field and temperature dependent, though the most efficient systems show surprisingly high and relatively field-independent separation efficiencies. Whether excess thermal energy (from excitation above the band gap) assists charge separation is also unclear, with evidence presented for and against. Once separated, charges must reach their respective electrode avoiding recombination. Another advantage of the bulk heterojunction architecture is that it seems to inhibit bimolecular recombination. The observed bimolecular recombination rate in efficient cells is found to be much less than the predicted Langevin recombination rate. This difference is believed to be related to the phase-separated structure with electrons and holes occupying separate regions and thus less likely to meet.

A number of different electron acceptors have been used in combination with conjugated polymer donors, including fullerene derivatives, electron accepting polymers and inorganic nanocrystals. The $C_{60}$ or $C_{70}$ derivatives such as PCBM (see Fig. 7) have proven to be the most effective electron acceptors. The power conversion efficiency record is currently 8.4 % (reported by Konarka Technologies Inc.) with the best literature-reported efficiency 7.4% (see Fig. 7). Efficient organic solar cells can also be realised (efficiency ~8%) with evaporated multi-layer small molecule devices similar to the structure of multi-layer small molecule LEDs. While these efficiencies still have a way to go to match inorganic solar cells (e.g. crystalline-Si 25%, CIGS 20%, amorphous-Si 10%), it is worth spending a moment to reflect on just how efficient organic cells are. Despite the excitonic nature of organic semiconductors and relatively low mobilities, internal quantum efficiencies approaching 100% have

been achieved. This is remarkable and shows that the process of converting absorbed photons to collected charge can be extremely efficient.

From an energy perspective, internal losses associated with charge transfer limit the open-circuit voltage and hence the power conversion efficiency. For example, the device in Fig. 7 has an absorption onset of ~1.7 eV, yet exhibits an open-circuit voltage of 0.75 V. Thus, nearly 1 V has been lost in internal processes. A key challenge is recovering this lost energy without affecting other device processes. It is unclear how much of this energy is 'lost' and how much is actually used for driving various device processes. Thus the ultimate efficiency achievable by OPVs is uncertain, with new materials continuing to produce record efficiencies.

Other strategies to increase the device efficiency include increasing the absorption out to the near-infrared (while maintaining the photocurrent collection efficiency) and developing higher mobility materials that will allow thicker films to be used. Finding an alternative to indium–tin oxide for the transparent electrode is also a key issue with ITO-coated substrates representing a substantial component (50% or greater) of the manufacture cost. Device stability is a further issue, though 4000 hour lifetimes at 65°C/85% rel. humidity have been recently reported by Konarka.

## Summary and outlook

Organic semiconductors are an interesting class of materials with unique properties that open up new manufacturing possibilities and device applications. The field brings together researchers from a range of backgrounds including synthetic chemistry, materials science and device physics. A number of technologies are already in the process of commercialisation with the real potential of making the future more flexible.

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## ABOUT THE AUTHOR


**Dr Chris McNeill joined Monash University in March 2011 as a Senior Lecturer and Future Fellow within the Department of Materials Engineering. After obtaining a PhD at the University of Newcastle, McNeill spent six years at the University of Cambridge, UK, as a Research Associate and an Engineering Physical Science Research Council (EPSRC) Advanced Research Fellow. At Monash he will work in collaboration with a team within the functional materials space working on solar energy.**

**McNeill is currently engaged in research that aims to enable the development of a new generation of low-cost electronic devices based on semiconducting plastics. His other research interests include polymer solar cells, organic field-effect transistors, structural properties of organic semiconductor films and synchrotron-based soft x-ray techniques. In addition to his Future Fellowship, McNeill is also the recipient of a Larkins Fellowship from Monash University. He can be contacted at christopher.mcneill@monash.edu.**

# The European Extremely Large Telescope

Fig. 1. An artist's impression of Gleise 581c, a super-earth discovered using HARPS at the ESO 3.6-m telescope [courtesy ESO].

**Jason Spyromilio**

**Breakthroughs in our understanding of astrophysical phenomena and discoveries of new classes of objects have often come about when facilities exploring new wavelength regimes or providing greatly enhanced sensitivity have been built. By virtue of being first on the scene – in 2009 we celebrated the 400th anniversary of the invention of the telescope – ground-based optical telescopes have led the way through a succession of ever larger and more powerful facilities.**

Since the 1930s large optical telescopes, the advent of radio astronomy and more recently space-borne infrared and X-ray missions have profoundly changed our view of the universe. Within the last 100 years we have moved from a world-view containing our Galaxy and within it some nebulae to a universe that is 13.7 billion years old populated by hundreds of billions of galaxies and consisting, approximately, of 5% baryonic matter, 25% dark matter and 70% dark energy. The universe is, by definition, the biggest physics laboratory and a telescope is one kind of apparatus we can use to probe its constituents.

In the late 1990s with a number of 8- to 10-m class optical/near-infrared telescopes in full operation it became apparent that while spectacular discoveries were being made, a number of questions would only be addressed with even larger telescopes. The direct imaging of extra-solar planets provides an excellent backdrop

for the need of another step in telescope size [1]. The discovery in 1995 of the first extra-solar planet by Michel Mayor and Didier Queloz (Geneva Observatory), using the radial velocity method, was followed up by many telescopes and instruments dedicated to the search, for example, the High Accuracy Radial Velocity Planet Searcher (HARPS) at the European Southern Observatory's 3.6-m telescope at La Silla [2] – see Fig. 1. However, direct imaging of planets has been a rare occurrence with the targets often far from the parent star and rather massive. Imaging a planetary system similar to our own remains beyond the capabilities of existing instrumentation.

Achieving the contrast necessary to image a planet close to its parent star ($\sim 10^{-10}$) is extremely challenging. The details of the telescope engineering necessary cannot be addressed in such a short article as this, but as a minimum it is clear that the sharper (higher Strehl ratio) the image of the parent star the easier the task of extracting the light of the faint planet next to it will be. Making the image of the parent star as small (angularly) as possible is a necessary prerequisite. This in turn, by virtue of diffraction, requires that the telescope primary mirror be as large as possible and correction of the atmospheric turbulence a necessity. For the purposes of this article, we shall not discuss albedo, optimum wavelength range, coronography techniques, etc. A telescope well above 30 m in diameter is needed for the quest of an image of another earth.

## How big can a ground-based optical/near-infrared telescope be?

To achieve the necessary optical performance (surface errors of order a few nm) telescope mirrors are typically made of polished low thermal expansion coefficient glass (or glass ceramic) materials dimensioned to be mechanically stiff (thereby minimising the effects of gravity). Until recently mirrors have been thick and heavy making the supporting mechanics sturdy and expensive. Polishing technology also limited the focal ratio of the mirrors to be relatively low, around f/3, making telescopes long and the domes in which they were housed large. The Palomar 200-inch telescope dome is similar in dimensions to St Peter's cathedral in Rome. In the 1980s three breakthroughs revolutionised telescope building [3]. Segmentation of the primary mirror reduced the total weight of the telescope optics by almost an order of magnitude. The invention of novel polishing techniques made possible fast (f/1) mirrors, and the usage of active optics to manage the shapes of thin mirrors and maintain the optical properties of the telescopes in closed loop, all combined to create new paradigms. The 10-m Keck telescopes on Mauna Kea, the European Southern Observatory's Very Large Telescope (four 8.2 m) on Paranal in Chile and Carnegie's Magellan (two 6.5 m) telescopes at Las Campanas (Chile) are examples of these technologies in routine and scientifically extremely productive operation [4].

Until these breakthroughs, telescope sizes had increased by a factor of two in diameter every twenty years. Now, behemoths as large as the OverWhelmingly Large (OWL) 100-m telescope could be considered and conceptual designs for such telescopes were developed. By the mid-2000s with the scientific rationale consolidated, three extremely large telescope (ELT) projects got underway. In United States, two teams are developing designs for ELTs and Australia, through the ANU and Astronomy Australia Limited, is a partner in one of them, the 27-m Giant Magellan Telescope. In Europe, the ESO has developed a detailed design for a 40-m class European Extremely Large telescope (E-ELT), spending over 60-million Euro on industrial contracts for design and prototyping activities over the past four years.

The top level scientific and technical requirements for the E-ELT project were established in 2006 following a period of extensive community consultation with five working groups established by the then director-general of ESO Catherine Cesarsky. The baseline design, approved by the ESO Council in December 2006, is for an adaptive telescope [5] to be located at the best possible site. The telescope should be able to image a rocky planet around a G-star within 10 parsecs.

## The optical design

A telescope with over 1000 $m^2$ collecting area incorporating adaptive optics requires an optical design that departs from the conventional two aspheric mirror solution. The E-ELT design is based on a three mirror anastigmat employing an aspheric ellipsoidal primary mirror at f/1, a large (>4-m) convex aspheric secondary mirror directing the beam through an intermediate focus down to a 4-m mildly aspheric concave mirror at the vertex of the primary. Two flat mirrors extract the light sending it to the focal plane instrumentation. The first flat mirror (approximately 2.7 m in diameter) is located very close to the intermediate focus and pupil of the telescope. It is the adaptive mirror that corrects

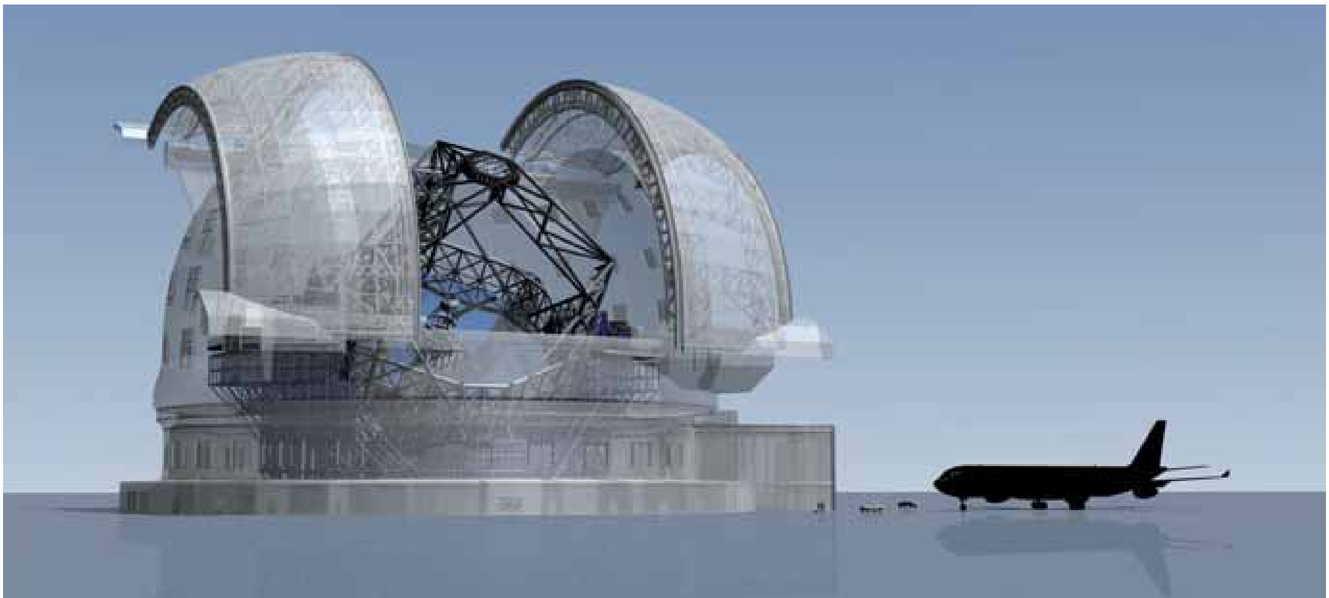
Fig. 2. The scale of the E-ELT dome and telescope in comparison to an Airbus A340 aeroplane [courtesy ESO].

for telescope and atmospheric aberrations and enables the telescope to deliver diffraction limited images. The fifth mirror is used to steer the beam to the Nasmyth foci and correct for image plane motions due to windshake of the telescope mount.

The primary mirror is formed from over 700 aspheric hexagonal segments in families of six segments each 1.45-m point-to-point and 50 mm thick. All mirrors are actively controlled for position and, with the exception of the fifth mirror, also for shape. Four wavefront sensors patrol the field of view of the telescope and provide closed loop feedback to the over 20,000 control points that ensure the optimal performance of the telescope.

## The telescope mount

The telescope mount uses a rocking chair design. One of the challenges in the design phase has been to minimise the deflections of the supports of the optics under gravity and thermal loads, while maintaining the necessary stiffness in the structure to resist excitation by the wind. The resulting structure weighs over 4000 tons before the payloads are added. The first eigen-frequency is above 2.4 Hz, a very respectable performance for a movable steel structure almost 70 m tall and 50 m wide – see Fig. 2. The deflections of the primary mirror cell due to gravity are below 10-mm and the decentering of the secondary with respect to the primary is below 6 mm for the full range of elevations. The entire structure and all hosted units are designed to withstand significant earthquakes.

The mount uses hydrostatic oil bearings in both altitude and azimuth to minimise friction. Three tracks at 9, 37 and 54 m diameter at azimuth and both the altitude cradles are provided with bearings. Direct drive motors move the structure with reference to absolute encoders co-located with the drives. Maximum speeds of 2 degrees/sec are needed to minimise the time between successive observations and to reduce the size of the blind spot any altitude–azimuth mounted telescope has close to the zenith. Actuators are used to increase the stiffness of the cross altitude structure and reduce the deflections of the main mirror cell as the elevation changes.

## The mirrors

Each of the primary mirror segments has to be supported and actuated to maintain the correct position and shape with respect to the rest of the optical system – see Figs 3 and 4 below. The polishing of an off-axis asphere with six long edges is in itself particularly difficult. To do this 700 times (actually closer to 1000 times including the additional mirror that is used to replace units that are being re-coated on an 18-month cycle during operations) in a period of five years requires significant investments not only in polishing infrastructure, but also in metrology techniques.

During the design phase the project office contracted the manufacture of two sets of seven prototype aspheric segments. This work has been particularly successful overall with fully compliant prototype segments being provided. Different polishing techniques have been explored including fully robotic polishing after cutting, robotic polishing followed by cutting and ion-beam

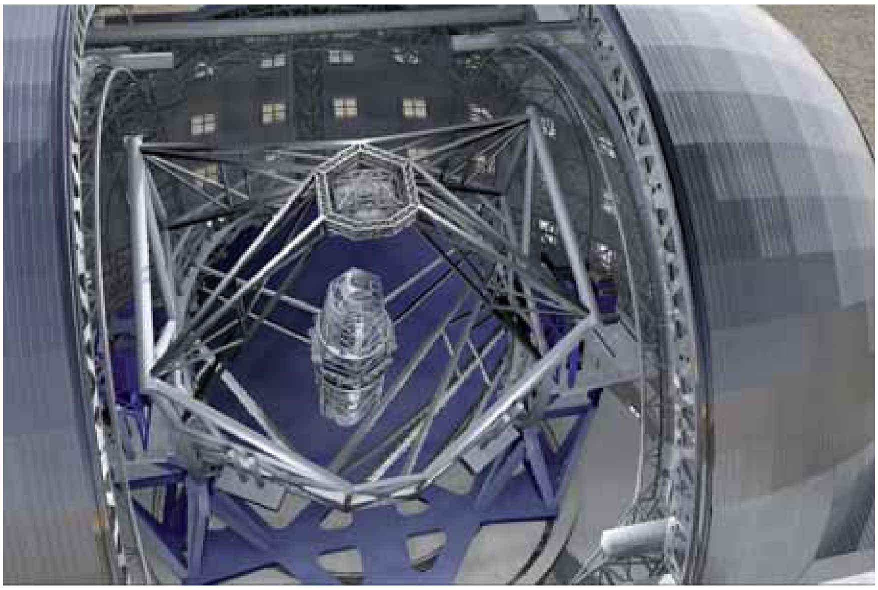

**Fig. 3. A view inside the E-ELT showing the telescope mirrors and Nasmyth foci [courtesy ESO].**

finishing, and stress mirror polishing followed by ion beam finishing. All techniques are capable of delivering suitable segments and significant effort has been focused on the optimisation of the industrialisation of the processes.

The support of each segment relies upon a twenty-seven point 'whiffle tree' incorporating 12 warping harnesses. These torque the whiffle tree pivots creating an imbalance that in turn results in forces being applied to the mirror segment. In this way active optics is built into each segment enabling modifications of its shape and compensating for polishing, gravity and thermal errors. Each support incorporates three position actuators that move the entire segment assembly in piston and tip-tilt to compensate for the deflections of the telescope mount support structure. Two fully functional sets of prototype supports based on independently developed industrial designs have been built under contract to ESO. A number of low power position actuators using voice coil and piezo technologies with nanometric precision over a 15 mm travel have been manufactured for the project.

The position of a segment relative to its neighbours is monitored by inductive edge sensors. Each segment sports 12 sensors measuring relative piston with nanometric precision and, with slightly less demanding accuracy, shear and gap. Prototype systems have been developed and tested under contract to the E-ELT project office. The fully integrated mirror assemblies are currently under test in a dedicated facility near the ESO headquarters in Garching, Germany.

The secondary and tertiary mirrors have been the subject of extensive industrial studies both in manufacturing and support. The secondary mirror is particularly challenging as it is convex and very large, which makes impractical conventional (e.g. Hindle sphere) testing of the piece during polishing. A test setup employing large (1.5-m) transmission optics (matrices) has been established as the baseline. The support of the mirrors is active based on voice coil actuators and the mirror cells are mounted on substantial hexapods to enable the active management of the telescope collimation.

The jewels in the telescope optics are the quaternary adaptive mirror and the fifth mirror that corrects for tip-tilt. The inclusion of these optical elements allows the telescope to maintain a stable focal plane. Additionally, it relaxes the requirements on the optical performance of other elements and the mechanics of the telescope itself. Without these mirrors built into the telescope the feasibility of the system could be questioned. The fast primary mirror which minimises the mechanical dimensions of the telescope implies a higher sensitivity to collimation errors, and a number of problems that in classical telescopes are quasi-static (e.g. field aberrations) can easily move into the dynamic range (a few Hz). The 7000-actuator 1-kHz adaptive quaternary mirror will not only correct for the turbulence in the earth's atmosphere, but also the telescope aberrations.

The design office has contracted two independent industrial consortia to develop prototype systems of the necessary systems and to test them in realistic environments. Moreover, a full-scale system is being developed for the VLT telescopes. Similar systems are in operation at telescopes in Arizona. The fifth E-ELT mirror is a 3 × 2.5-m flat mirror that is required to correct for the tip-tilt of the telescope at 10 Hz. The mirror itself is to weigh less than 500 kg and have a first eigen-frequency around 300 Hz. This is a very challenging optical component and the design office has considered both lightweight glass and silicon carbide solutions. A scale-1 fully functional prototype of the tip-tilt stage was delivered to the project in the middle of 2010.

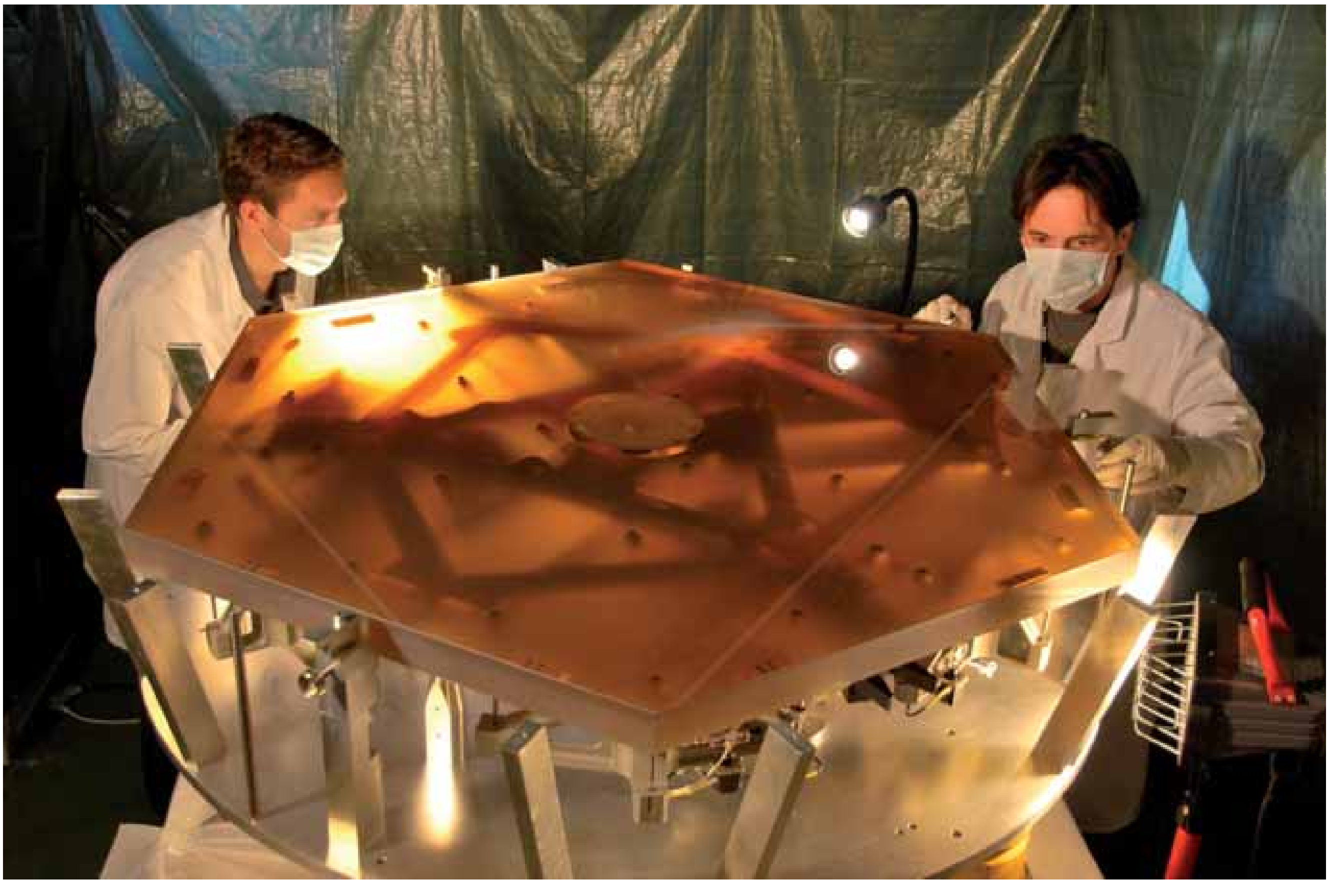

**Fig. 4. A polished aspheric segment is inspected after integration with its support. Over 1000 of these hexagonal segments will be manufactured for the E-ELT [courtesy ESO].**

## The dome

The telescope is to be housed inside a substantial dome with a footprint 100 m in diameter and height exceeding 80 m. The challenges of a rotating structure the size of a football field, providing a light, water and almost air-tight air-conditioned environment during the day and protection from the wind during observations at night are plentiful. Noteworthy is the approximately 2 MW of power required to be delivered to the dome motors to accelerate the 5000 ton structure from stationary to full rotation speed in 5 seconds. The dissipated power must not turn into heat that would warm the air close to the telescope beam thereby spoiling the seeing properties of the site and, of course, the reverse problem has to be considered when the dome stops rotating. Flywheel systems will be employed to protect the electrical circuits of the instrumentation attached to the telescope, as well as the stand-alone power generation system that the observatory will require.

Following extensive site testing, including data provided under a cooperative agreement with the US led thirty-meter project (TMT), the site for the telescope has been selected to be Cerro Armazones in the Chilean Atacama desert. This location has 89% clear weather and exceptional seeing and other atmospheric properties. While the Chilean desert skies provide exceptional atmospheric conditions for observations, unfortunately the ground is prone to earthquakes. The telescope and dome foundations are to be seismically isolated in both horizontal and vertical directions and extensive earthquake engineering and analysis has been undertaken. This is not novel in telescope engineering and already at the ESO VLT both passive and active systems are in place to protect the telescope and its optics in cases of severe earthquakes.

## The instrumentation

The telescope beam is provided to an array of instruments located at the two Nasmyth and the coude focus. Over the past four years over 100 institutes in the 15 member states of the European Southern Observatory have participated in a massive community effort to design the instrumentation for the E-ELT. At first light a diffraction limited near-infrared imager/spectrograph and an integral field diffraction limited near-infrared spectrograph are to be offered to the astronomical community, while an

annual multi-million Euro commitment is expected to maintain the instrumentation at the highest level throughout the lifetime of the telescope.

## Project planning and management

With a projected cost for the telescope exceeding 1 billion Euro, the E-ELT design has been focused on cost and risk management as well as engineering excellence. Cost and component selection has been part of the design, rather than the procurement and construction. In this context the project has avoided the normal science project path of designing in-house and then procuring the manufacturing of components. This has invariably led to designs that differ from those familiar to conventional industrial production.

The E-ELT has focused on 'competing' the design of the telescope not only for performance, but also in terms of cost from the first instance. By requiring design work to be accompanied by commercially binding offers to execute the designs, the suppliers and the project have been acutely aware of the commercial tradeoffs necessary at the earliest stages. This is embodied in the use of 'Front End Engineering Design' contracts to industry. Significant financial and manpower resources have been allocated to maintain competition throughout the design phase. The bulk of the project costs are now established based on firm fixed price offers from industrial partners and there is confidence that the project is programmatically as well as technically feasible.

This short article cannot address the huge efforts made in system engineering, requirements management, interface generation, risk management and performance analysis throughout the design phase of the project. However, it is worth noting that many of the control algorithms for the primary mirror have been successfully tested by the E-ELT team on the 10.4-m segmented Gran Telescopio Canarias (GTC) during technical time provided by Spain to ESO as part of that nation's accession agreement. Additionally, the control systems for the E-ELT are being deployed as upgrades to the existing Paranal infrastructure, thereby reducing the debugging and development time for the complex computer and control infrastructure.

The project construction timescale is supported by the industrial suppliers and first light can be achieved eight years after the start of construction.

## Current status

The phase B detailed design phase for the E-ELT concluded with an external review towards the end of 2010 and the project was deemed to be technically ready to move to construction. Optimisation of the design is ongoing while awaiting approval for construction by the ESO Council. Located only 20 km from the existing infrastructure at Paranal, the E-ELT will complement the existing facilities currently operated by the ESO.

In late 2010 Brazil joined the ESO as its 15th and first non-European member state. It is possible that an early green light for construction of the E-ELT could be given during 2011.

## Notes

[1] For the full science case – see www.eso.org/sci/facilities/eelt/science.

[2] The European Southern Observatory is an intergovernmental treaty level organisation founded in 1962 to provide state-of-the-art research facilities to its users – see www.eso.org.

[3] Jerry Nelson (U. California, Santa Cruz), Roger Angel (U. Arizona) and Ray Wilson (ESO) were awarded the prestigious Kavli Prize for Astrophysics in 2010 for their pioneering work in telescope design.

[4] Australia is a participant in the twin 8.1-m Gemini telescopes.

[5] Adaptive optics employs a deformable mirror that compensates for the aberrations introduced in the image of the star by the earth's atmosphere, thereby restoring the telescope to its diffraction-limited performance. It is a technology widely used in ground-based telescopes.


## ABOUT THE AUTHOR

**Jason Spyromilio received his BSc (1986) and PhD (1989) from the physics department at Imperial College in London. Following a postdoctoral fellowship at the Anglo-Australian Observatory in Australia, he was appointed a staff astronomer at the AAO in Marsfield, Sydney. In 1994 he moved to the European Southern Observatory in Munich as a full-time astronomer. He headed the commissioning of the Very Large Telescope (VLT) at Paranal, and served as director of the La Silla Paranal Observatory, before returning to Munich in 2006 to head the E-ELT project office. Jason is a distinguished visitor at the AAO.He can be contacted at jason.spyromilio@eso.org.**

## Lastek

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Designed to minimize the moving mass, lightweight sample holders are integrated into the stage and represent the only moving component. This unusual design allows the three axes of motion to have matched resonant frequencies and step response times. Equal 3-axis speed is particularly useful for applications like 3D particle tracking. The Nano-LPQ uses internal position sensors utilizing proprietary PicoQ™ technology to provide absolute, repeatable position measurement with sub-nanometer resolution under closed loop control.

The Nano-LPQ is LabView™ and C++ compatible and is supplied with Mad City Labs' Nano-Route™3D software, for ease of use.

**Features:**
- Low profile, high speed, XYZ motion
- Built-in sample holders
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**Typical Applications:**
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The Nano-LPS Series is the lowest profile 3 axis piezo nanopositioning systems suitable for applications such as super resolution (SR) microscopy and force microscopy. The Nano-LPS series continues the innovative design approach originally introduced by Mad City Labs. At only 20mm tall and an 83mm wide center aperture, the Nano-LPS series is designed for practical microscopy users interested in nanoscale phenomena. The Nano-LPS series features up to 300 microns of motion per axis and picometer precision under closed loop control. The low height of the Nano-LPS Series allows it to be easily integrated into existing inverted optical microscopes. Like the related Nano-LP Series, the Nano-LPS Series is ideal for demanding microscopy applications which require long range travel, fast scan rates, and three axes of motion.

Mad City Labs proprietary PicoQ™ sensors enable picometer position noise with ultra high stability, which is important for demanding applications such as SR microscopy techniques.

**Features:**
- Lowest profile 3-axis nanopositioner available
- Large aperture for standard 3" slides
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**Typical Applications:**
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- Optical trapping experiments
- Fluorescence imaging
- Alignment
- Single molecule spectroscopy

### Ocean Optics acquires Sandhouse Design

Ocean Optics extended its product family after acquiring Sandhouse Design, LLC.

Sandhouse developed a unique line of high-powered LED light sources for research and spectroscopic applications.

These products have been widely used in biotechnology, process control and industrial applications.

### LED Light Sources

These ergonomic and smartly designed fiber-coupled LED light sources are ideal for fluorescence, spectroscopy and general fiber illumination applications. The Ultra LED high-power light sources can be operated in continuous or external trigger modes. Available in UV, VIS and Infrared.

### SIR Scanning Spectrometers

The SIR Scanning Spectrometer Series from Ocean Optics provides you a range of fiber-based spectral data collection in a detection instrument that is built to last and always reliable.

These SIR Scanning Spectrometers feature USB 2.0-compliant interfaces that provide fast data transfers. Plus, the included software can be used to control all of your SIR spectrometer's functions as well as analyse data.

The SIR spectrometer family includes:
- SIR-1700: 400-1700 nm
- SIR-2600: 0.9-2.6 µm
- SIR-3400: 1-3.4 µm
- SIR-5000: 2-5 µm
- SIR-6500: 3.0-6.5 µm

### Deep UV LEDs

Sandhouse Deep UV LEDs are available in a wide range of wavelengths and package sizes. These devices are manufactured using AlGaN/GaN technology, which enables a new generation of high band-gap energy opto-electronics devices, able to perform down to 240 nm.

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- Wavelengths diode lasers: 405, 445, 488 and 640 nm (375, 473, 660, 785 nm and others on request)
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The individual lasers are efficiently combined and delivered free beam or via an all-in-one PM/ SM fibre output. The microprocessor controlled system enables flexible OEM integration. High speed analogue and digital modulations allow fast switching of laser wavelength and intensity.

TOPTICA's ingenious COOL$^{AC}$ technology automatically aligns the system with a single push of a button. This feature ensures a constant optical output level even under strongly varying ambient conditions and completely eliminates the need for manual realignment - making the iChrome MLE the most advanced multi-line laser system on the market.

- Single mode, polarisation maintaining fibre output or free beam COOLAC technology for highest coupling efficiency, ultimate stability and drop-shipment capability
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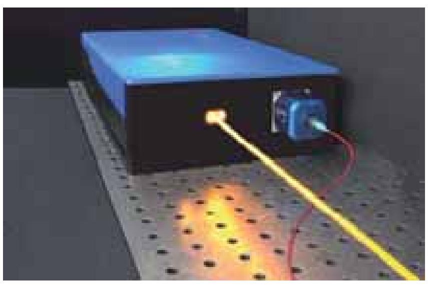
The iChrome TVIS laser system is a fibre laser with the flexibility to set automatically the laser output to any wavelength in the visible (488 – 640 nm). The coherent laser output ensures that the visible light exhibits the best intensity noise performance and the use of polarisation maintaining optical components a stable linear polarisation of the fibre coupled output beam is achieved. The entire laser system is extremely user friendly: No alignment procedures of any optical components distract the user from the main task – to produce results.

## DL-RFA-SHG pro @ 589nm 2 Watt, single line for sodium cooling



The new DL RFA SHG pro is a narrow-band tunable continuous wave laser for sodium cooling. The system is based on a near-IR diode laser in the successful 'pro-design' (DL 100/pro design, 1178 nm), with a subsequent Raman fibre amplifier (RFA) and a resonant frequency doubling stage (SHG pro).

The DL RFA SHG pro features a spectral linewidth below 1 MHz and 20 GHz mode-hop free tuning. For system operation, no water cooling and no external pump is required. The power scalable approach of the DL RFA SHG pro also offers solutions for other high power applications such as sodium LIDAR, medical therapy or super resolution microscopy. Customised systems with higher output powers up to 10 W are available on request. Wavelengths between 560 and 620 nm will soon be available as customised solutions.

## FemtoFiber pro – the product family is expanded

After the successful introduction of the FemtoFiber pro IR, NIR and SCIR models, TOPTICA is now taking the final step to also include the remaining system variants such as tunable visible (TVIS), tunable near-infrared (TNIR) and tunable ultra compressed pulse (UCP). Options such as variable repetition rate (VAR) and a phase-locked loop Laser Repetition rate Control (LRC) by TOPTICA's well-established PLL-electronics are rounding up the FemtoFiber pro product family.

The first and fastest of the new models, UCP, shows short pulses in the range down to 13 fs, the fastest available on the market from a turnkey SAM modelocked fibre laser system.

The TVIS expands the super-continuum generation (SCIR) by a tunable second harmonic generation and allows transferring femtosecond pulse generation into the visible wavelength range from 490 to 700 nm.

The TNIR variant finally adds a new feature to the FemtoFiber pro family. As opposed to the TVIS, it uses the high-band continuum (>1560 nm) for second harmonic generation. This continuum part is a solitonic pulse and therefore needs no pulse compression. The output wavelength can be tuned from 800 to 1100 nm. This variant was not previously available in the FFS product family.

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# Warsash

## Lightweight Benchtop Vibration Isolation

Warsash Scientific is pleased to announce a new lightweight benchtop vibration isolation system from Kinetic Systems, Inc. Specifically designed for portability, the ELpF can be easily repositioned on the benchtop, even with a load and in float. Its unique, self-contained design provides this without causing damage to the vibration isolators.

An economical alternative to heavyweight models, the Ergonomic Low-Profile-Format platform provides vibration isolation for sensitive devices. It features a load capacity of 100 or 300 lbs. in a lightweight, ergonomic system.

The platform has a low profile (only 3" high), uses a small tabletop (16" x 19" standard), and weighs 40 lbs., making it very portable. Ergonomic features include gauges tilted upward for easier viewing and recessed handles for easy carrying.

Designed for use in laboratories and Class 100 cleanrooms, the ELpF platform is ideal for supporting atomic force microscopes, microhardness testers, analytical balances, profilometers, and audio equipment.

Self-leveling and active-air isolation give the platform low natural frequencies (1.75 Hz vertical, 2.0 Hz horizontal) and typical isolation efficiencies of 95% (vertical) and 92% (horizontal) at 10 Hz.

Other tabletop sizes can be customized per specifications. The top, which can be ordered with or without mounting holes, can be aluminum plate, ferromagnetic stainless steel, plastic laminate, or anti-static laminate.

For more details on this or other vibration isolation equipment, contact sales@warsash.com.au

## Real-Time Operating System for Systems Integration

PI (Physik Instrumente), the leading manufacturer of piezoceramic drives and positioning systems, offers a real-time module as an upgrade option for the host PC and also the connection of the GCS (PI General Command Set) software drivers. The module is based on Knoppix-Linux in conjunction with a pre-configured Linux real-time extension (RTAI).

The use of real-time operating systems on the host PC allows it to communicate with other system components, e.g. a vision system, without time delays with discrete temporal behavior and high system clock rate.

A library which is 100% compatible with all other PI GCS libraries is used for the communication with the real-time system. All PI GCS host software available for Linux can be run on this system.

The real-time system running in the real-time kernel can be used to integrate PI interfaces and additional data acquisition boards for control. Open functions to enable you to implement your own control algorithms are provided. Data, such as positions and voltages, is recorded in real time, and pre-defined tables, with positions, for example, are output in real time to the PI interface and to additional data acquisition boards.

You can program your own real-time functions in C/C++, MATLAB/SIMULINK and SCILAB.

The system includes a PI GCS server, which allows the system to be operated as a blackbox using TCP/IP, via a Windows computer, for example.

The system can be installed on a PC or booted directly as a live version from the data carrier. A free demo version with restricted functionality is available.

For more information on the real time operating software or other PI positioning equipment, contact sales@warsash.com.au

## E-618: 3.2 kW Peak Power for New Piezo Amplifier

Available from Warsash Scientific is the new PI (Physik Instrumente) E-618 high power amplifier for ultra-high dynamics operation of PICMA® piezo actuators.

The amplifier can output and sink a peak current of 20A in the voltage range between -30 and +130V. The high bandwidth of over 15kHz makes it possible to exploit the dynamics of the PICMA® actuators. This type of performance is required in active vibration cancellation and fast valve actuation applications.

The E-618 also comes with a temperature sensor input to shut down the amplifier if the maximum allowed temperature of the piezo ceramics has been exceeded. This is a valuable safety feature given the extremely high power output.

The E-618 is available in several open-loop and closed-loop versions with analogue and digital interfaces.

For more information on these and the range of other PI products, contact sales@warsash.com.au
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## New Sensors Improve Precision of S-340 Tip/Tilt Mirror

Warsash Scientific is pleased to announce the release of the new S-340 piezo tip/tilt mirror platform from PI (Physik Instrumente), equipped with new high-resolution strain gauge sensors.

The S-340 now achieves a resolution of 20nrad at angles of 2mrad about both orthogonal axes.

This large mirror platform is used for optics with diameters of up to 100 mm (4 inches) and achieves a resonant frequency of 900Hz for a mirror of 50 mm diameter.

The S-340 can be operated by the new, low-cost E-616 controller. Together, they form a compact, high-performance solution for beam control and image stabilization as employed in astronomy, laser machining or optical metrology, for example.

For more information on the S-340 Tip/Tilt Mirror platform or other Positioning equipment from PI, contact sales@warsash.com.au

## Coherent

### PI-MAX3 Intensified CCD Cameras

Princeton Instruments' PI-MAX series of intensified CCD cameras has set the standard for time-resolved imaging and spectroscopy for almost a decade. Now Princeton's PI-MAX3 takes ICCD performance to a new level with order of magnitude speed improvements and a host of new features to allow easier and more accurate time-resolved imaging.

PI-MAX3 is available in formats of 1024 x 1024 pixels for imaging and 1024 x 256 pixels for spectroscopy. Video frame rates can be achieved in the imaging format and

spectral rates of thousands of spectra per second can be achieved. Most importantly, the camera allows sustained gating rates up to 1 MHz, a 20-fold improvement over previous designs.

The camera includes the improved SuperSynchro timing generator, SyncMaster clock output, a compact 'one-box' design, convenient GigE interface and much, much more.


### Light-Field 64-bit Acquisition Software

From the world leaders in optical spectroscopy and CCD/EMCCD/ICCD technology comes LightFieldTM, an all-new 64-bit data acquisition platform for spectroscopy and imaging. LightFieldTM combines complete control over Princeton Instruments' cameras and spectrometers with easy-to-use tools for experimental setup, data acquisition and post-processing.

LightfieldTM ensures data integrity via automatic saving to disc, time stamping and retention of both raw and corrected data with full experimental details saved in each file. LightFieldTM works seamlessly in multi-user facilities, remembering each user's hardware and software configurations and tailoring options and features accordingly. The optional, patent-pending IntelliCal package is the highest-performance wavelength calibration software available, providing up to ten times greater accuracy across the entire focal plane than competing routines.

Features include:

- Immediate data acquisition upon launch
- Progressive disclosure - contextual menus ensure that only relevant options appear
- Graphical hardware configuration builder ensures that system elements work exactly as the end user expects
- Dark gray GUI reduces monitor brightness; monitor dims automatically during acquisition
- All experimental parameters are saved to data file headers - no more searching old notebooks for data acquisition settings
- Automatic light saturation warning with pseudocolour
- Multiple regions of interest can be defined in a single window
- Save and reload experimental settings and share between multiple users
- Configurable setting dock holds preferred commands
- Control multiple cameras via multiple instances of LightField
- Drag-n-drop data into Excel, Paint and Notebook or export to TIFF, FITS, CSV etc.
- Peak find function works with both narrow and broad lines
- IntelliCal provides up to ten times improved accuracy

### eXcelon…CCD and EMCCD sensitivity redefined

Princeton Instruments and Photometrics are pleased to announce the launch of new eXcelon back-illiminated charge-coupled device (CCD) and electron-multiplication CCD (EMCCD) detector technology that will revolutionise scientific imaging and spectroscopy.

New eXelon sensors provide excellent photon-detection capabilities across a wide spectrum, from 200 to 1100nm, and are particularly beneficial for applications requiring enhanced sensitivity in the blue and near-infrared (NIR) region, as illustrated below. In addition, eXcelon back-illuminated sensors significantly reduce etaloning (the problematic appearance of fringes).

When eXelcon technology is applied to EMCCD devices, the result is a detector with sub-electron read noise, superb sensitivity, low dark current, little (if any) etaloning and high frame rates.

New eXcelon technology will be featured in Princeton Instruments' PIXIS and ProEM deep-cooled cameras and is available in several pixel-array formats:

- 1340 x 100 and 1340 x 400 CCD cameras for spectroscopy
- 512 x 512 and 2048 x 2048 for imaging

The technology is also available in 512 x 512 and 1024 x 1024 ProEM EMCCD cameras.

These new eXcelon-enabled cameras will target a wide variety of applications in both the life and physical sciences. Examples include astronomy, Raman spectroscopy, live-cell imaging confocal imaging, total internal reflection fluorescence microscopy (TIRFM), Forster resonance energy transfer (FRET), Bose-Einstein condensate (BEC) imaging, solar cell inspection, as well as super resolution techniques such as STORM and PALM.

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# CONFERENCES IN AUSTRALIA 2011–2012

**28 June – 1 July 2011**
**Twenty-fifth International Union of Geodesy and Geophysics (IUGG) General Assembly: Earth on the Edge**
Melbourne Convention & Exhibition Centre, VIC

**1 – 3 July 2011**
**Astronomical Society of Australia's Harley Wood Winter School**
Adare House, Victor Harbour, SA

**4 – 8 July 2011**
**Astronomical Society of Australia's Annual Science Meeting**
University of Adelaide, SA

**7 July 2011**
**Inaugural Queensland Postgraduate Physics Research Conference**
Queensland University of Technology, Brisbane, QLD

**19 – 22 July 2011**
**Fifteenth International Conference for Women Engineers and Scientists (ICWES15)**
Adelaide Convention Centre, SA

**12 – 13 August 2011**
**Summer School on Functional Imaging in Radiotherapy: Australasian College of Physical Scientists & Engineers in Medicine**
Darwin, NT

**14 – 18 August 2011**
**Engineering and Physical Sciences in Medicine and the Australian Biomedical Engineering Conference**
Darwin Convention and Exhibition Centre, NT

**28 August – 1 September 2011**
**IQEC/CLEO Pacific Rim 2011**
Sydney, NSW

**16 – 19 October 2011**
**Australian Radiation Protection Society Conference**
Melbourne, VIC

**31 January – 3 February 2012**
**Thirty-sixth Annual Condensed Matter & Materials Meeting**
Charles Sturt University, Wagga Wagga, NSW

**25 February 2012**
**Queensland Astronomy Education Conference (QAEC)**
Brisbane, QLD

**4 – 11 July 2012**
**Thirty-sixth International Conference on High Energy Physics, ICHEP2012**
Melbourne Convention and Exhibition Centre, VIC

**5 – 10 August 2012**
**Nuclei in the Cosmos 2012**
Cairns Convention Centre, QLD

**18 – 23 November 2012**
**Fifteenth International Conference on Small-angle Scattering, SAS 2012**
Sydney, NSW


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