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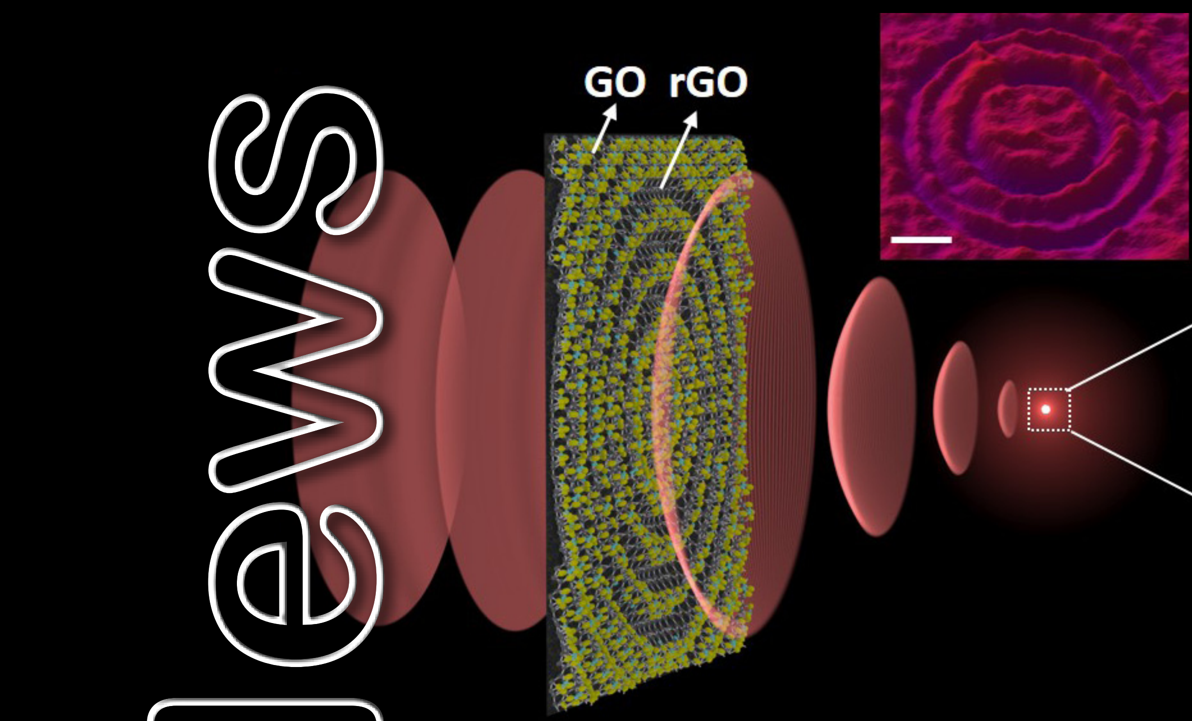

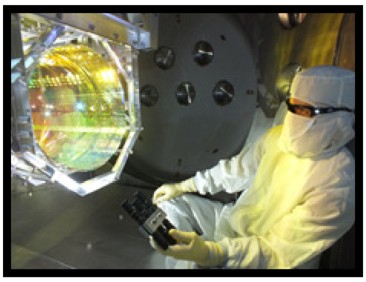

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AOS News is the official news magazine of the Australian Optical Society. Formed in 1983, the Society is a non-profit organisation for the advancement of optics in Australia. Membership is open to all persons contributing to, or interested in, optics in the widest sense. See the back page (or the AOS website) for details on joining the Society.

Submission guidelines

The AOS News is always looking for contributions, especially from AOS members. Here is a short summary of how to make a submission.

How can you submit?

► The easiest way is by email. We accept nearly all file formats. (Famous last words!).

► Submitted articles will be imported into an Adobe InDesign file. It is best if the diagrams and other graphics are submitted as separate files. All common graphics formats are acceptable, but the resolution must be in excess of 300d.p.i.. Be aware that all colour diagrams will be rendered in grayscale, so if you do use colours, choose colours that show up well in grayscale.

► When using Greek letters and mathematical symbols, use font sets such as Symbol or MT Extra. Please avoid using symbols that are in Roman fonts, where the Option or Alt key is used; e.g. Opt-m in Times font on the Mac for the Greek letter mu.

► If using TeX, use a style file similar to that for Phys Rev. Letters (one column for the title, author and by-line, and two for the main body). The top and bottom margins must be at least 20mm and the side margins 25mm. Submit a pdf file with the diagrams included (no page numbers), as well as copies of the diagrams in their original format in separate files.

► If using a word processor, use a single column. If you do include the graphics in the main document, they should be placed in-line rather than with anchors, but must be submitted separately as well.

What can you submit?

- Scientific Article
  A scientific paper in any area of optics.
- Review Article
  Simply give a run down of the work conducted at your laboratory, or some aspect of this work.
- Conference Report
- News Item
- Book Review
- Cartoon or drawing

Reviewing of papers

On submission of a scientific or review article you may request that the paper be refereed, and if subsequently accepted it will be identified as a refereed paper in the contents page. The refereeing process will be the same as for any of the regular peer reviewed scientific journals. Please bear in mind that refereeing takes time and the article should therefore be submitted well in advance of the publication date.

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Articles

Departments

Cover Pictures:

- Upper: Graphene oxide (GO) films offer a number of possibilites for new photonic devices. Here is a schematic of wavefront manipulation by a GO lens. Inset is an optical profiler image of the GO lens with a 2 µm scale bar, see page 29.
- Lower: Students from across Australia and New Zealand attended the IONS KOALA 2015 conference in Auckland, see page 11.
- Insets (left to right)
  - There were many demonstrations at the public lectures run by CUDOS at the University of Sydney to celebrate the International Year of Light throughout 2015, see page 8.
  - LIGO has a large range of optical components that were used in the recent detection of gravitational waves. See page 27 for more information on the role of Australian scientists in this project. Image credit: Matt Heintze/Caltech/MIT/LIGO Lab.

Submission Of Copy:
Contributions on any topic of interest to the Australian optics community are solicited, and should be sent to the editor, or a member of the editorial board. Use of electronic mail is strongly encouraged, although submission of hard copy together with a text file on CD will be considered.

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Copy Deadline
Articles for the next issue (June 2016) should be with the editor no later than 15 May 2016, advertising deadline 8 May 2016.

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http://www.optics.org.au

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President's Report

The recent announcement from the LIGO Scientific Collaboration and VIRGO Collaboration for their detection of gravitational waves, confirming Einstein's prediction from 100 years ago was a great reminder of how optics continues to have a key role in addressing a range of challenging research topics. I like the way the specific event was described: "around 1.3 billion years ago, around the time multicellular life was starting to spread on Earth, a pair of black holes collided and released a torrent of gravitational energy into the cosmos. Today, physicists announced they had spotted that energy here on Earth." Not all AOS members may realise the Australian connection with this discovery. Researchers from the Australian National University and the University of Adelaide contributed to Advanced LIGO, along with groups from several US universities. On behalf of AOS congratulations are extended to the researchers and scientists so involved.

Each year, Science & Technology Australia, of which AOS is a member, organises "Science meets Parliament" in which the research community has an opportunity to consider the role of science in the nation and for individuals to meet with parliamentarians. This year it took place on 1 and 2 March, in Canberra, and AOS was pleased to be represented by Prof Daniel Shaddock from ANU, and a member of the Australian consortium associated with the LIGO project, thereby providing connectivity between our decision-makers and those involved with the gravitational wave project. AOS members will be able to read about his experiences in Science meets Parliament 2016 in a later edition of AOS News.

Attendees at ANZCOP 2015 will remember Prof. Ursula Keller, the Director of the National Center of Competence in Research for Molecular Ultrafast Science and Technology at ETH Zurich. She was supported by the Geoffey Frew Fellowship from the Australian Academy of Science but as other commitments precluded her from attending to all the requirements of the Fellowship at the end of 2015 AOS members had a further opportunity to hear her speak this month.

Members will be pleased to know that our website and membership systems are in the process of being modernised, and I thank Council members especially Baohua Jia our Honorary Treasurer and Matt Collins. Thank you for persisting with paying your AOS membership!

I trust that the range of activities organised for the Year of Light around the country provided members with good opportunities to both understand better the role of light in our wider discipline, and as outreach to the broader community especially school students. The Council is keen to pursue further efforts to help policy-makers understand how light underpins so much of modern technology.

This year marks the centenary of the birth of Aleksandr Prokhorov, in the Atherton Tablelands region, who was one of the co-winners of the 1964 Nobel Prize in Physics for the invention of the laser. AOS, supported by the AIP, has been successful in obtaining National Science week funding to organise events in far north Queensland to highlight the laser during Science Week (in August). There are a number of organisations that have been highly supportive of this initiative, and with the involvement of a local secondary school physics teacher a major public event will be held in Atherton.

Finally, can I remind members that each year AOS awards a range of prizes to its members working in all aspects of optics? The AOS medal, named after WH (Beattie) Steel, one of the founders of the AOS, is awarded for an outstanding contribution or contributions to the field of optics in Australia, while the Geoff Opat Early Career Researcher Award recognizes an outstanding early career researcher for their achievements. AOS student members are eligible to receive the Postgraduate Student Prize which supports travel to international conferences. AOS corporate member Warsash also generously sponsors the Science Communication Prize in Optics providing an avenue for students to exercise their ability to communicate their research to a broader audience. Finally, the AOS also recognises technical achievement through the AOS Technical Optics award. Members are urged to nominate their colleagues and students for these awards so that their outstanding contributions to the field can be recognised and rewarded. The deadline is 30 April and more information can be found on the AOS web page: optics.org.au.

Stephen Collins
AOS president

Editor's Intro

Welcome to another issue of AOS News. We have a range of articles, with details of some of the International Year of Light events that took place last year and a report on the KOALA conference as well as articles on graphene oxide films and astrophotonics. Other items in this issue include an article about Australia's involvement in the gravitational wave discovery and our 'Optics in Everyday Life' section, which looks at periscopes. I hope you enjoy reading them all.

The start of the year tends to be very busy for many academics in Australia as this is when grant proposals for research funding are due. A lot of people have concerns about the amount of time that this takes for those involved, not only with writing detailed proposals, but also for the reviewing and panels that people may have to sit on as part of the process. Whilst there is obviously value in having a research plan, when the success rate for grants and fellowships is low due to low levels of research funding (project grant success rates for the ARC and NHMRC were 17.7% and 13.7% respectively last year), this raises the question of how much time and money is used in this process for little return. There have been many discussions about this, and I think it is interesting to consider some of the alternatives that have been suggested as well as methods that are being used elsewhere.

Last year Ronald Germain suggested in *Cell* that the US project grant funding systems should change to fund people rather than the projects themselves. This would reduce the impact of needing high quality preliminary data which limits novelty and creativity as well as disadvantaging early career researchers (ECRs). He proposed using only the track record to rank applications, reducing the number of applications and giving consensus in ranking, and proposed giving funding to the top ranked people for 5-7 years before a review to continue, expand or reduce funding. This simpler process would save time and money. There are fellowship schemes both here and overseas that already do this to some extent, but the number of these available is low (approx. 315 fellowships per year for ARC, 325 for NHMRC). Most Australian fellowships can only be received once by each recipient and they often don't give much research support so that project grants are usually needed in addition to any fellowship.

In 2014 a group at Indiana University proposed a method of collective allocation of science funding in *EMBO reports.* This was again funding scientists and not projects and avoided the need to write and review proposals. All researchers would be given a base level of funding each year and would also share out a certain amount to other applicants based on who they think would do well with the funding. With rules to avoid conflicts of interest in place this could allow a better spread of funds with at least some money allocated to ECRs. They suggested that this would be simpler, cheaper and fairer than the traditional funding systems, with better prospects of innovation and chance discoveries and that it could be implemented alongside traditional schemes rather than replace them.

A recent an article in *eLife* showed that National Institutes of Health (NIH) peer review scores within the top twenty percent of proposals are actually not a good indicator of productivity for funded grants. They suggest that reviewers can tell which applications are very strong, but ranking within these excellent proposals not only seems to be arbitrary, but the productivity and success of applications within the top range is very hard to predict. They recommend that reviewers should just identify the top twenty percent of applications and then award funding within this group on a random basis, saving the time that is normally taken to review and rank these in detail. A lottery system for these proposals would also save time for applicants not having to re-write unsuccessful submissions if they fall within this group.

All of these articles look at health and medical research funding in the US, but could be expected to apply to other areas of research funding across the globe and are certainly interesting ideas to consider. The concept of backing researchers themselves is not completely new and is not always well-received, with worries that a poorly implemented 'people not projects' scheme could still overly advantage those with seniority and coming out of larger labs. Expanding the process to allow all those in the funding pool to allocate extra top-up funds is an interesting twist on this, with both of these suggestions not requiring lengthy proposals. A lottery system is a more novel idea, although the authors note that one is already in place for a small number of proposals in New Zealand through the Explorer Grants Scheme, which only awards three grants per year. This deals with seed funding only, but is a full lottery system once proposals have been judged to fit certain criteria with researchers not named during assessment of the application. An additional advantage of a lottery system listed by the authors of the article is that seeing how many good projects remain unfunded entirely due to chance may help to improve the overall levels of research support as the ideal situation would be that the amount of funding available is restored to the level where all deserving projects can be funded.

I hope you enjoy this issue of AOS News,

Jessica Kvansakul
Editor

A Century of Nobel Prizes in Light - Research that Changed the World!

by Martijn de Sterke

CUDOS at the University of Sydney celebrated the International Year of Light with a series of light-themed public lectures throughout 2015.

UNESCO declared 2015 to be the International Year of Light. CUDOS at the University of Sydney celebrated this by organising a set of seven light-related presentations intended for a general audience; the box lists the presenters and their presentations. These lectures showed how light and light research has made our life more comfortable, how it is instrumental in dealing with some of the global challenges we are facing, and how it helps us understand our place in the universe. The format of the presentations came from the realisation that since their inception in 1901, a very large number of Nobel Prizes have been awarded for light-related research in physics, chemistry and physiology/medicine. The presentations used Nobel Prizes awarded in this period as guidance to exploring how scientific ideas developed throughout the last century. Of course the term "Nobel Prize" also adds some cachet to an event. My own presentation on Solid State Lighting for example, started with the statistic that approximately 25% of electricity is used for lighting, and that more efficient lighting can thus strongly reduce our energy use. I then traced the efficiency of the key lighting technologies through history, starting from the oil lamp (~0.1 lm/W), incandescent light (~16 lm/W), fluorescent light (~70 lm/W) to LEDs (~300 lm/W). The efficiencies here are rough indications and of course depend on the details of the light source's design. Incidentally, though LEDs are significantly more efficient than other light sources, the largest jump in efficiency came with the invention of the incandescent light bulb! The presentation then traced the history that led to LED lighting, using the following Nobel prizes as stepping stones: Bohr (1922 - light emission); Townes, Basov and Prokhorov (1964 - lasers); Shockley, Bardeen, Brattain (1956 - semiconductors); Alferov, Kroemer (2000 - semiconductor heterostructures); Akasaki, Amano and Nakamura (2014 - blue semiconductor lasers). It then concluded with a description of current lighting technologies and how they are likely to develop in the coming years.

The first six presentations were given by academics from the University of Sydney, while the final one, in early December, coinciding with the SPIE Micro+Nano Materials, Devices, and Applications Conference, was given by international photonics superstar Professor Michal Lipson from Columbia University in the US. The presentations attracted a wide audience, including several groups of high school students, members of the general public, university academic and non-academic staff, and undergraduate and postgraduate university students. The presentations were followed by an engaging set of hands-on demonstrations of virtual reality, microscopy, an IR camera and a Michelson interferometer, amongst others, and also had a demonstration of the Laser Harp, the University of Sydney's Optics Student Chapter contribution to the 2015 Vivid Sydney Festival.

Feedback from the audience has been excellent: researchers appreciated learning about light-related research that is outside

IYL lecturer Joss Bland-Hawthorn with a School class from Marist Brothers Eastwood.

INTERNATIONAL YEAR OF LIGHT 2015 AUSTRALIA

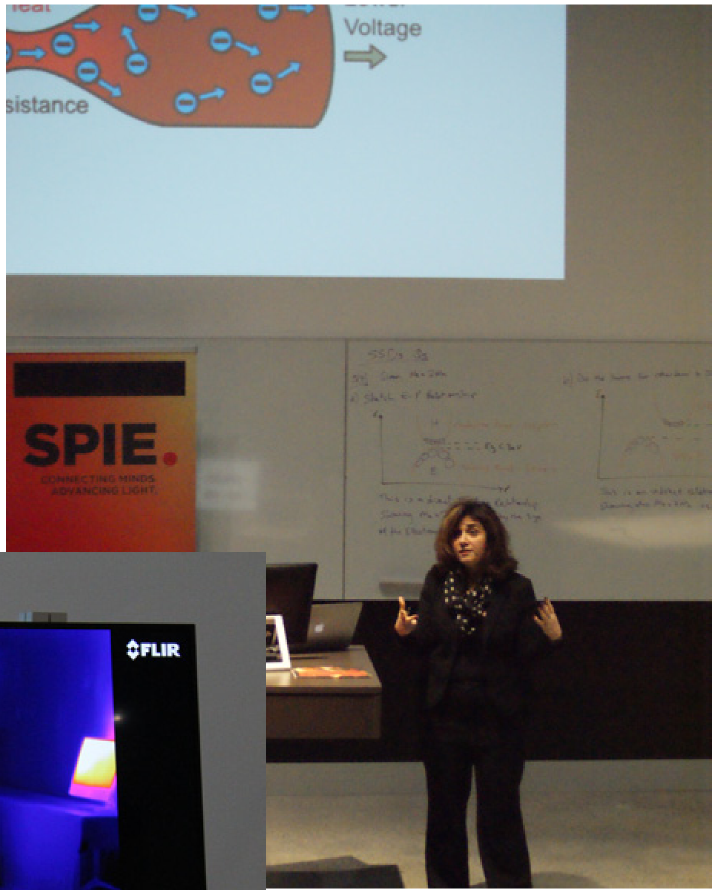
- Martijn de Sterke: "Blue light and dark screens - semiconductor LEDs and the lighting revolution"
- Andrew Doherty: "The story of the photon: from Einstein to Glauber"
- Maté Biro: "Shedding light on life through a powerful lens: the microscope"
- Min Chen: "Milestones in the light-driven process of photosynthesis"
- Ben Eggleton: "Light and the information revolution"
- Joss Bland-Hawthorn: "In search of the oldest light in the universe"
- Michal Lipson: "Computing at the speed of light"

Video and audio recordings of the presentations can be found at http://www.cudos.org.au/nobelprizesForLight.shtml

Details of the IYL public lecture series held during 2015.

their own area of expertise, while members of the general public enjoyed learning how optics and photonics underpin our daily lives. High school students were also excited about the opportunity of being photographed with the Lecturer. Though the International Year is now over, we are considering continuing the lecture series into 2016!

Martijn de Sterke is with CUDOS, School of Physics, University of Sydney.



Michal Lipson presents her work.

Postgraduate student Scott Brownless uses liquid nitrogen to demonstrate an IR camera.

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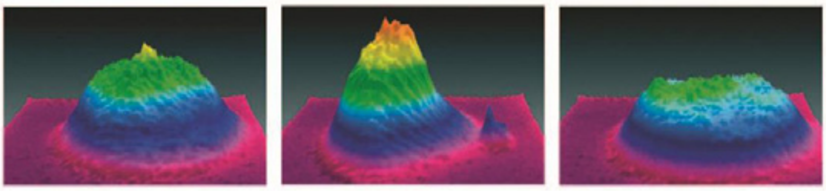

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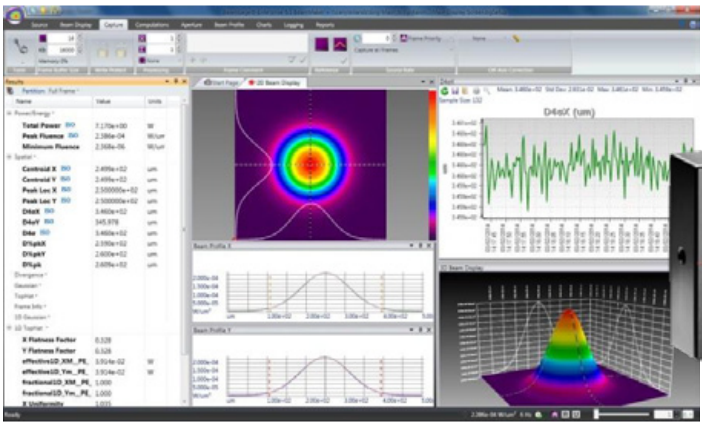

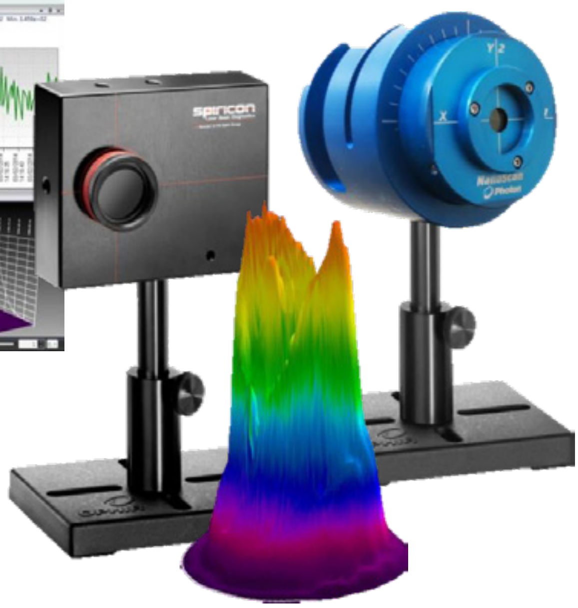

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IONS KOALA 2015

by Bianca Sawyer

IONS KOALA is the Conference on Optics, Atoms and Laser Applications held annually in Australia and New Zealand.

The conference is organised for students, by students, and brings together a large group of Honours, Masters and PhD students from New Zealand, Australia and beyond. KOALA aspires to foster an environment where young researchers can share their expertise, discuss new ideas, relax, and socialise while building long-lasting networks that will continue to support them throughout their careers.

IONS KOALA 2015 was co-hosted as a collaboration between the University of Auckland OSA Student Chapter and the University of Otago OSA and SPIE Student Chapter and was held from 22nd – 27th November on the University of Auckland Campus, in the heart of the Auckland CBD and home to many world class research centres including the Photon Factory and a large branch of the Dodd Walls Centre for Photonic and Quantum Technologies.

Since the inaugural conference in 2008 in Brisbane, KOALA has been continually expanding and evolving. KOALA 2015 was the second ever kiwi-KOALA and we are very proud to say that it was the biggest and most international to date, with a total of 107 attendees from institutions across 10 different countries: New Zealand, Australia, Japan, China, Singapore, Malaysia, the UK, France and Austria! Of these, 98 were students.

We were fortunate to be hosting KOALA during the UNESCO International Year of Light and Light-Based Technologies (IYL 2015). The scientific programme featured five truly inspiring plenary speakers working in a variety of fields across optics and photonics. The talks focused on trends in optical communications, advances in atomtronics circuits, uses of ultra-short pulses, medical imaging and surgical robots, and insights into careers and connections in photonics. Four of our plenary speakers travelled from the USA and the UK to be a part of this event, for which we are very grateful!

Some of the organising committee at the registration desk.

One of these was Nobel Laureate William D. Phillips of the Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland, who generously gave his time to present both a plenary talk and a public lecture, entitled “Einstein, Time and Light”. The public lecture was an entertaining, informative and down-to-earth account of the way that gases can be cooled to ultracold temperatures for use in atomic clocks, included many exciting experimental demonstrations, and was thoroughly enjoyed by the ~500 strong audience (including many children).

Attendees discussing presented research during the poster session.

The majority of student attendees also made amazing contributions to our program and helped to create an active, fun and supportive atmosphere. There were a total of 5 tutorials, 45 oral presentations and 35 poster presentations throughout the course of the week, covering a wide variety of topics such as laser machining, spectroscopy and atom optics, and all presented to an exceptionally high standard.

As well as its strong scientific program, KOALA boasts extended social and professional development opportunities, which kicked off on Monday evening at the Industry and Innovation Night. This event was inspired by the Industry

Nobel Laureate Professor William Phillips giving a demonstration during his public lecture.

Workshop held at IONS KOALA 2014 and served as a platform for networking between conference attendees and representatives from the Australasian optics community; an opportunity for students to find out more about the exciting world of optics and photonics industry and innovation. The evening began with a keynote presentation by Dr Michelle Stock, who gave conference delegates her insights on the career path for young researchers after completing their academic career. Specifically she referred to her own experiences developing her startup company and consulting firm. This was followed by a panel discussion where Michelle was joined by three other industry and innovation experts from a variety of backgrounds. The panellists answered questions from the audience about their careers, advice on getting into industry and innovation, and the relationship of industry and academia, to name a few.

Wednesday was our social day, where attendees took the day to kick back and relax while socialising with their peers and enjoying some of the things that Auckland has to offer. Many spent the day swimming, walking and playing soccer at St Heliers Bay, a seaside suburb east of the Auckland City Centre with one of the region's most picturesque beaches overlooking Rangitoto Island and Waitemata Harbour, while others stayed in the city and checked out art galleries, museums and the Sky Tower.

Our Conference Dinner was held on Thursday at Mecca Stonehouse in Mission Bay, where attendees enjoyed a sit-down meal in a covered outdoor area overlooking the beach and unbeatable views of the Hauraki Gulf. As well as a way to wrap up the conference and socialise with conference attendees, the evening was dedicated to celebrating IYL2015 and the outreach efforts of our conference delegates during the year. It served as an opportunity to look back on the year that has been IYL 2015 via a series of student presentations, reflect on what we have all achieved and spark up conversations around how we can continue to promote light and light-based technologies beyond 2015.

On behalf of the IONS KOALA 2015 Organising Committee I'd like to express my genuine thanks to our invited speakers, generous sponsors, student presenters and other attendees, all of whom helped to make IONS KOALA 2015 a success!

In 2016, IONS KOALA will be returning back across the ditch to Melbourne thanks to a joint effort by the students of the OSA and SPIE student chapters at Swinburne University of Technology and Monash University; Shaun, Sam, Xuewen and team – good luck, and bring on KOALA 2016!

Bianca Sawyer is the IONS KOALA 2015 Co-Chair and University of Otago OSA and SPIE Student Chapter President.

Industry discussion panel.

IONS KOALA 2015 group photo, taken before the conference dinner at Mission Bay. Rangitoto Island can be seen in the background.

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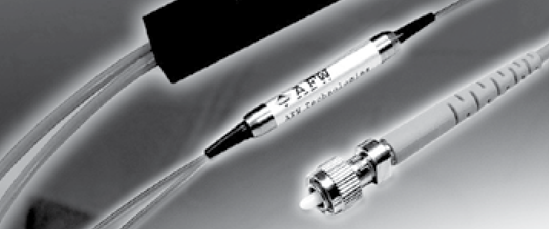

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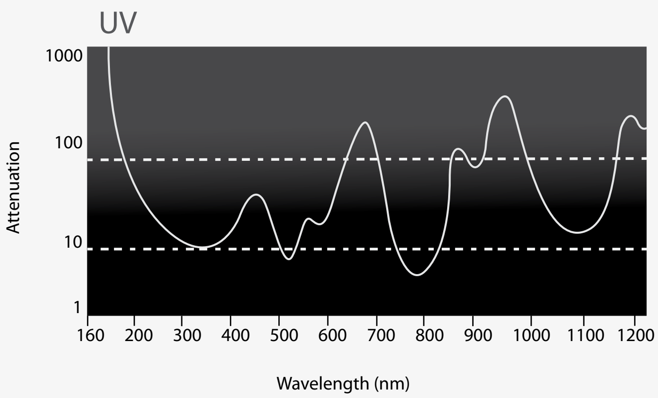
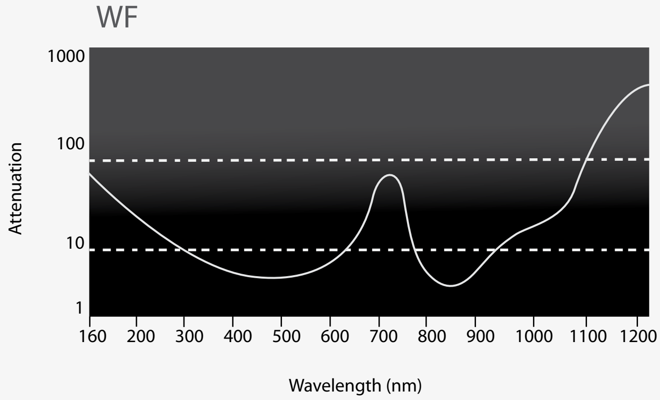
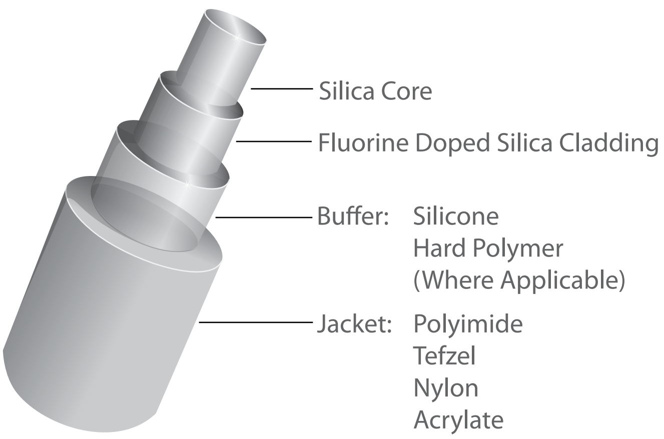
Sensors	Low NA 0.12, standard NA 0.22
UV photolithography	Pure silica core and doped fluorine silica cladding
Laser welding / soldering / marketing	Core/cladding 105/125, 100/140, 200/220, 400/440, 600/660, 800/880 um
Laser delivery	Jacketed with 3mm PVC material and connector boots behind the connector
Nuclear plasma diagnostics	
Analytical instruments	1 to 3 meter or custom lengths
Laser diode pigtailing	FC, SMA 905 or ST type connectors
Semiconductor capital equipment	FC, ST or SMA adaptors







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News

Congratulations to Chennupati Jagadish

AOS member Professor Chennupati Jagadish was named a Companion of the Order of Australia in the Australia Day honours. The ANU nanotechnologist works on a wide range of projects, including biomedical imaging, developing new lasers for telecommunications, and developing lightweight, efficient solar cells. He describes one of his most exciting current projects as designing a 'brain on a chip' - encouraging the growth of artificial, trainable neurons, with exciting potential for future computing power.

Chennupati is vice-president of the Australian Academy of Science, founder of the Australian Nanotechnology Network, and head of the ANU's Semiconductor Optoelectronics and Nanotechnology Group.

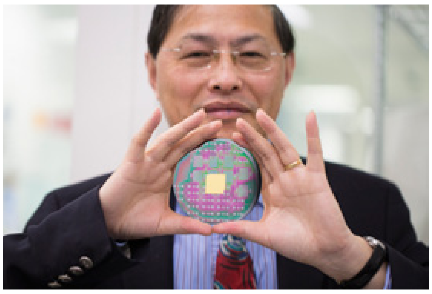
Professor Chennupati Jagadish

Australian research in the news

Twisted light

Min Gu's groups at Swinburne and RMIT recently published a paper in Science showing how they can control the angular momentum of light at the nanoscale using an integrated photonic chip. Twisting light helically gives it angular momentum, and this acts as an extra variable that can be controlled to pass even more information down an optical fibre. The team have developed a chip with a series of nano-apertures and nano-grooves that allow the on-chip manipulation of twisted light. This has the potential to achieve ultra-high bandwidth, with six-orders of magnitude of increased data access compared to current technology.

Original article: DOI: 10.1126/science.aaf1112

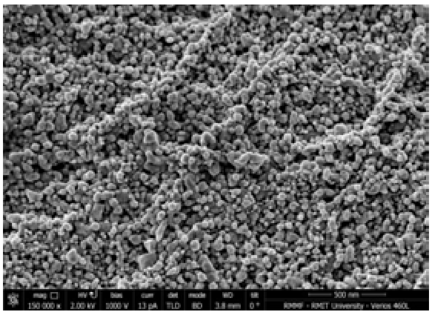


Professor Min Gu with the photonic chip that controls the angular momentum of light. Image credit RMIT.

Nanoparticles could be used to make self-cleaning fabric

A group at RMIT has developed silver and copper nanoparticles that can be grown on fabrics and degrade organic matter when exposed to light. In an article published in Advanced Materials Interfaces, they explain how self-cleaning materials can be created by coating textiles with stable nanostructures. The nanostructures absorb energy when exposed to visible light, and this energy can be used to break down organic matter. Stains on the test material were shown to break down under light exposure, the fastest in only six minutes. The next step is to test organic compounds that are of interest to consumers.

Original article: DOI: 10.1002/admi.201670025



Close-up of nanostructures grown on cotton textiles. Image credit RMIT.

Call for Papers Abstracts Deadline: 3 May 2016

Advance Registration: 8 August 2016

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Astrophotonics is Looking Up – The Rise of Photonics in Astronomy

by Joss Bland-Hawthorn

Astrophotonics emerged in about 2001 with a view to exploring new ways of making observations in optical and infrared astronomy. Over the past decade, the field has made real advances in both photonics and instrumentation. The author is the recipient of the 2015 WH "Beattie" Steel Medal awarded by the Australian Optical Society.

Biophotonics, neurophotonics, nanophotonics – every year, it seems that a new cross disciplinary field is born. But astrophotonics has been with us since about 2001 when I was Head of Instrument Science at the Australian Astronomical Observatory (AAO) exploring new enabling technologies for astronomical instrumentation. This field is now practiced in dozens of institutions around the world in the UK, France, Germany, Portugal, Canada, USA and beyond.

Pierre Kern (University of Grenoble) and I have already written introductions to this field [1, 2]. Rather than rehashing old material, I'd like to update you on recent developments and successes, some from the Sydney environs and examples from overseas. I will also mention interesting linkages with industry.

I guess the overall goal of anyone involved in astronomical or space instrumentation is to achieve more, or to achieve more with less. Technology is always expensive and lead times to the first useful devices are measured in years rather than months. This is true of commercial industry where drug trials, for example, take a decade to deliver on a product. This also seems to be the case for enabling technologies in astronomy where, for example, after 20 years we are beginning to see the benefits of single conjugate adaptive optics (AO). In another decade we'll have mastered multi-conjugate AO (i.e. over a focal plane rather than simply on-axis).

Astrophotonics lies at the interface of photonics and astronomical instrumentation. Its goal is to manipulate light in new ways to enable new kinds of science or to do traditional astronomy in more effective ways. As I will explain, gradual improvements in AO strengthen the case for astrophotonics year by year.

I came to the University of Sydney in 2007 on an ARC Federation Fellowship with three goals: to show how instruments can be rendered much smaller and cheaper, and to develop complex filters for night-time observations. A third goal was to develop an astronomical instrument concept based on the new enabling technologies. By the end of 2012, my group managed to deliver on all three of the primary goals. The grant led to three new astronomical instruments: SAMI based on high-tech fibre bundles [3], GNOSIS and PRAXIS based on the new filters [4, 5] and the first microspectrograph for astronomy [6]. Microspectrographs are becoming commonplace in astronomy although these remain largely in the development phase – I will return to this development below. In a separate venture, in 2012, we managed to launch one of these devices on a high-altitude balloon in collaboration with Dr Iver Cairns, collect nice data from 30 km, and even retrieve the instrument from the South Australian outback.

I would like to recognise the extraordinary work of excellent Sydney-based researchers involved in the field. Staff member Dr Sergio Leon-Saval oversees many of the Sydney developments and manages contracts with overseas collaborators. Professor Peter Tuthill (PT) co-habits the SAIL lab space and runs a talented group focussed on infrared interferometry in all its guises. Dr Julia Bryant directs fibre bundle manufacture and testing and leads the Hector project (see below). Dr Seong-Sik Min continues to oversee the development of the Mach Zehnder and Sagnac interferometers for printing fibre Bragg gratings. Drs Chris Betters and Nick Cvetojevic lead the development of optical/IR microspectrographs for ground and space applications. We retain an outstanding working relationship with the AAO primarily through Dr Jon Lawrence (Head), Dr Simon Ellis, Dr Anthony Horton and joint positions through Drs Julia Bryant and Nick Cvetojevic. We have enjoyed a string of talented PhD students including Chris Trinh, Barnaby Norris (PT), Chris Betters, Richard Neo (with Dr Molina-Terriza), Emma Lindley, Sam Richards, to name a few. And then there are the superb industry year, summer vacation, 2nd year, 3rd year, Honours and annual overseas students (mostly French) who stay for up to 5 months.

Today, we have access to superb new facilities – the *Sydney Astrophotonic Instrumentation Labs* (SAIL) – directed by staff member Dr Leon-Saval and funded at present by my 2014 ARC Laureate Fellowship, a major University grant and ARC LIEF grants. This Fellowship will concentrate on generalising single-mode action in multimode photonics (e.g. filtering, switching, dispersion), and deliver a successor to SAMI, known as Hector, that will operate at the AAT by 2020 [7]. This instrument is a cornerstone of the CAASTRO-3D Centre of Excellence bid in 2016 (CI: Professor Lisa Kewley, ANU) and the next major night-time facility on the Anglo-Australian Telescope.

Adaptive optics

In the interests of brevity, let me focus on one of the main goals of astrophotonics – to focus most of the light from a telescope of any size onto a single-mode fibre or waveguide. Even under ideal conditions, the focussed light from a diffraction limited telescope is not ideally suited to couple efficiently to a single-mode photonic device for a number of reasons. For compactness, essentially all front-line telescopes have big holes on-axis to allow the beam to be folded and directed through the central hole. The distorted focussed image can be remapped to a Gaussian beam using phase-induced amplitude apodizing (PIAA) optics developed by O. Guyon. Moreover, huge

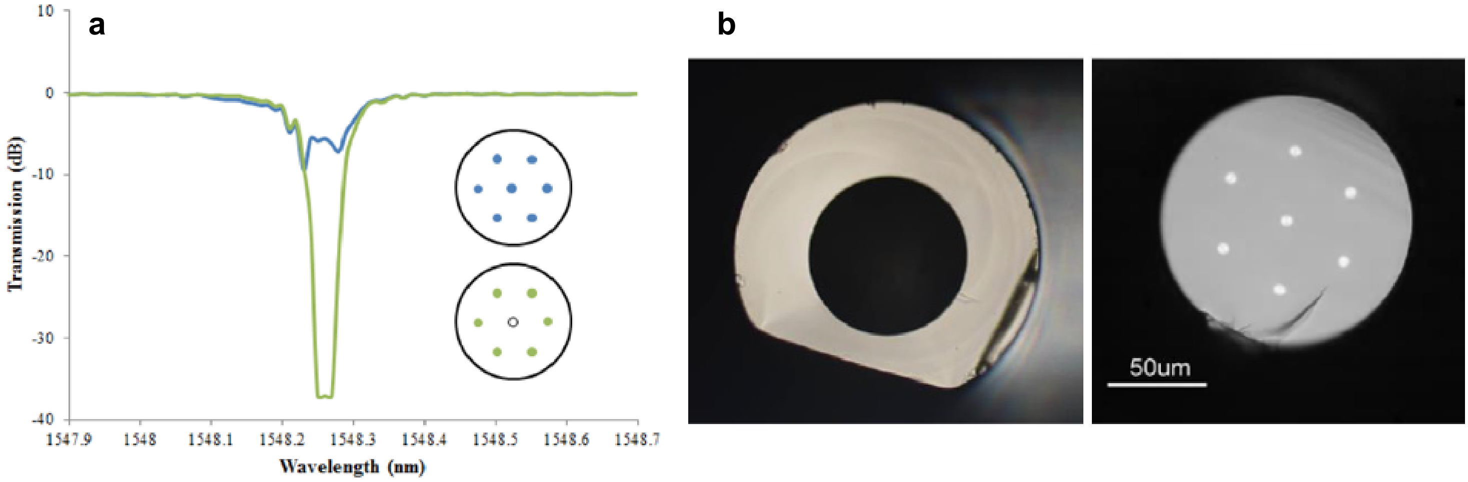


Figure 1. (a) Deep notch in transmission when illuminating a 6-core fibre Bragg grating (b) Special field flattening capillary to ensure even illumination across all cores [11].

improvements in MEMS technology over larger formats means that the turbulent wavefront can now be rendered flat. Both of these contribute to a much more stable and focussed beam of light. Already, the Subaru/Sydney collaboration has demonstrated 60% coupling efficiency of the 8m Subaru telescope, which is truly spectacular, and tells us in a sentence that AO+photonics has come of age [8]. In my 2015 “Frontiers in Optics” plenary talk in San Jose -- available online -- I talk about this and related work in detail. Just imagine the awesome power of focussing the light of a 25-40m behemoth efficiently into photonic devices through direct coupling! This prospect seems very real to me.

But even without perfect modal coupling to a single-mode fibre or waveguide, we have an elegant fall-back technology – the photonic lantern. We have been developing instruments that exploit these clever devices [9, 10]. Incoherent, or partially coherent, light received at the input propagates through a slow taper which transforms to a multi-core fibre. Each of these cores propagates in single-mode and feeds into an instrument. The light can be transformed by a conventional device (e.g. fibre Bragg grating, ring resonator), be collected up and fed back into a photonic lantern to generate multimoded output; alternatively, the light can be directed to a low-noise detector.

Multicore technology and fibre Bragg gratings

We continue to explore the power of multicore fibres and especially photonic lanterns feeding into identical gratings within these multicore structures. Emma Lindley’s thesis has focussed on how to get uniform gratings into these cores and her early results are impressive [11] (see figure 1). The goal is to greatly increase the complexity of the gratings and the number of cores in the fibres. Emma has recently published a video paper in Jove which explains some of the lab techniques in more detail: www.jove.com/video/53326?status=a55332k (figure 1b). Our earlier work was carried out in the near field with a Mach Zehnder arrangement which only allowed for printing to a depth of about 150 microns. We are now building a Sagnac interferometer to improve the depth of field of the coherent region which will allow us to treat a larger number of cores and fatter fibres.

Microspectrographs

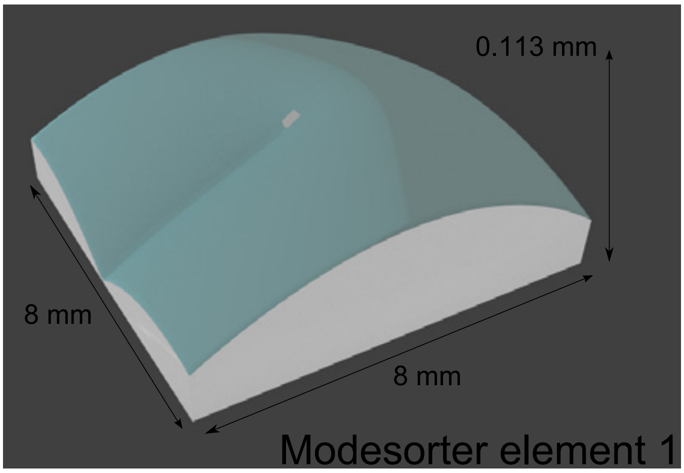
The SAIL labs pioneered the use of microspectrographs in astronomy a decade ago to usher in a new era of astronomical instrumentation. In many instances, we do not need to build huge monolithic spectrographs. This has been made possible with the photonic lantern which segments an arbitrary aperture into single-mode outputs, allowing the use of minimal diffraction-limited optical paths [e.g. 6, 8, 12, 13]. This technology is also able to incorporate compact laser combs for stability, and many other technology platforms.

These spectrographs have applications that go way beyond astronomy. We have successful collaborations with other departments, both in Australia and overseas. We work closely with Professor Salah Sukkarieh (Head of Field Robotics, University of Sydney) on the development of new sensors for his farm robots funded by Horticulture Australia Limited. Salah’s robots are already able to find their way around paddocks and orchards. Our goal is to detect unwanted bacteria using Raman and infrared spectroscopy building on our stabilised microspectrograph platform. Chris Betters and Sergio Leon-Saval already have a working prototype which they have used successfully on salmonella specimens at the Charles Perkins Centre. In a few weeks, they will be trialling the photonic Raman spectrograph on board a farm robot in the field.

Astronomy of the future – photonic orbital angular momentum

There is an aspect of light that is rarely exploited, i.e. optical or photon orbital angular momentum (OAM). Any paraxial optical field can be decomposed into a superposition of helical modes whose spatial profile is expressed as $A_k(r)\ \exp(ik\phi)$ with integer azimuthal index k and possessing OAM equal to $k\hbar$ per photon. The trademark of these modes is a twisted wavefront where the optical phase wraps around the centre of the mode from 0 to 2π radians, with k being an integer defining the OAM content of the mode. Any angular asymmetries of the wavefront will correspondingly change the distribution of OAM modes. Hence for photonic OAM, wavefront aberrations are of key importance and optics have to be carefully designed and manufactured (see figure 2).

Over the past decade, there have been half a dozen astrophysical papers claiming that the OAM signature could be observable in celestial sources. A recent paper even claims to have detected OAM from a bright star. So we have spent a couple of years looking at OAM generation, dispersion and detection, and the impact of adaptive optics in assisting



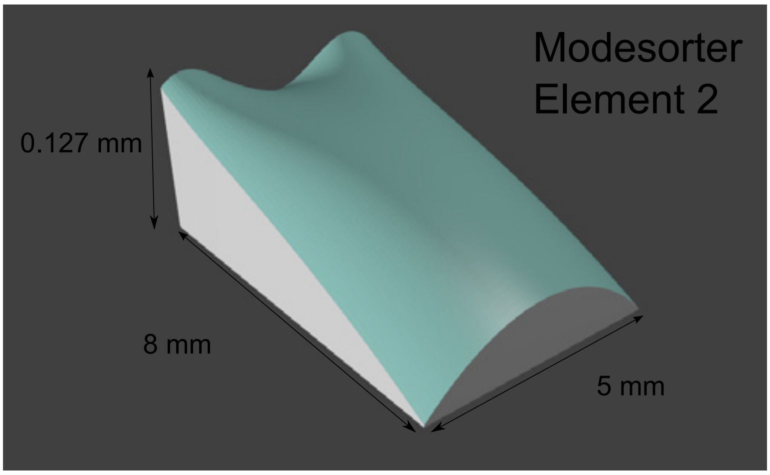


Figure 2. Strange free-form optics designed by Richard Neo (PhD) and manufactured for use within our photonic OAM spectrograph [15].

its detection [14, 15]. We have built a powerful OAM spectrograph that takes the input signal and sends the light at different k orders to different parts of the detector. The OAM spectrograph is quite complex and includes some very unusual optical elements (see figure 2). Our goal now is to try out this instrument on a small telescope before exploring its use with a full AO system.

Australia retains strong leadership in the field of astrophotonics although other international groups have grown their programs impressively (e.g. Potsdam, Maryland, Durham, Herriot Watt, Grenoble). We have broad interests across science but retain a strong focus on astronomy and space. Be sure to contact Sergio Leon-Saval (s.g.leon-saval@usyd.edu.au) if you'd like a tour of SAIL or want to discuss a possible collaboration.

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Joss Bland-Hawthorn is ARC Laureate Professor of Physics, University of Sydney.

The Australian Optical Society

AOS Prizes and Awards nomination deadline approaching!

Australian Optical Society members are reminded that the deadline for applications for all AOS awards is 30 April. Please consider applying or nominating students or colleagues. All applications and nominations are to be forwarded to the AOS Secretary. Membership of the AOS is an eligibility requirement for all awards.

AOS W.H. (Beattie) Steel Medal

The AOS WH Beattie Steel Medal is awarded for an outstanding contribution or contributions to the field of optics in Australia or New Zealand by a member of the Australian Optical Society. This Medal is the most prestigious award of the Australian Optical Society and is normally be presented only to a nominee at an advanced stage of his or her professional career with a strong and sustained record of authority, enterprise and innovation in the field of optics in Australia or New Zealand.

The AOS Geoff Opat Early Career Researchers Prize

This Prize recognizes an outstanding early career researcher for her/his contribution to the field of optics. The prize is $1500, awarded annually, and includes an invitation to give an extended presentation at the annual AOS conference. The winner of this prize will also write an article for AOS News.

AOS Postgraduate Student Prize

The Australian Optical Society wishes to encourage participation in national and international conferences by high-quality postgraduate students, and thus the Society has instituted the Australian Optical Society Prograduate Student Prize, which is a grant for conference travel valued up to $1500. Up to one award will be made in each year. Preference will be given in the selection procedures to applicants who intend to use the prize to attend and present their research results at a major conference outside Australia and New Zealand.

AOS Technical Optics Award

This award recognises those who have made a significant achievement in technical optics, not necessarily in a manner manifested by an extensive academic record or a traditional academic reputation. The work for which the award is made must have been carried out principally in Australia or New Zealand. Applications are encouraged from, but not restricted to, young optical workers. The winner will receive a prize consisting of $300 cash, one year’s free membership of AOS, and an invitation to attend the AOS conference and make an oral presentation of his or her work.

AOS Warsash Science Communication Prize in Optics

This Prize is open to AOS student members whose Honours, Masters or PhD research work has been accepted for publication in a refereed journal in the past year. The Prize may only be awarded once to any individual. A submission consists of a 300-word summary of the published research, written in the style of a New Scientist article or similar, explaining the significance of the applicant’s research project to a casual reader outside the field. The $500 Prize is sponsored by Warsash Scientific Pty Ltd.

For more information, visit optics.org.au

Product News

New Ultrafast Laser Delivers Femtosecond Pulses at 40W Average Power

Coherent has released Monaco, a diode-pumped ultrafast laser delivering 40µJ pulses at 1035nm, with repetition rate variable from single shot to 1MHz. Standard pulsewidth is <400fs and an option is available for variable pulsewidth from <400fs to 10ps.

Monaco has outstanding beam quality ($M^2 < 1.2$) making it ideal for demanding micromachining applications in research and industrial environments. Homogenous materials such as glass and metals as well as complex layered structures are readily addressed with Monaco's sub-400fs pulsewidth.

Finally, Monaco's reliability is assured through the HALT (Highly Accelerated Life Test) and HASS (Highly Accelerated Stress Screen) protocols employed during development and throughout production. Commonly used in the consumer electronics and automotive industries, Coherent has introduced HALT/HASS to the laser industry to bring an unrivalled standard of reliability and quality to laser-based manufacturing.

Astrella – 5kHz (>1.2mJ) option now available

Astrella is designed and manufactured to be at the forefront of an industrial revolution in ultrafast science, and is the culmination of several development projects. Coherent's expertise as the proven leader in developing and consistently improving high power amplifier systems is leveraged together with advanced, stress-testing techniques developed for the production of our commercial lasers used in demanding industrial applications. The Astrella is now available in a 5kHz repetition rate variation to better match throughput requirements when pulse energies are not the data-limiting factor.

- Energy >7mJ, 1kHz or >1.2mJ, 5kHz
- Pulse Width <35fs, or <100fs
- Stability <0.5% rms
- Beam quality M^2 <1.25

The Astrella is the new standard of both excellence and economy for amplified ultrafast, featuring:

- Integrated Vitara seed laser, new pump laser, *new* STAR regenerative amplifier and *new proprietary* sealed, compact stretcher/compressor for ultimate stability and reliability
- HASS*-tested at sub-component *and* system level for superior product quality and reliability
- All major sub-systems thermally-stabilised for reliable long-term performance
- Innovative, water-only cooled Ti:Sapphire rod assembly for improved beam quality and thermal management, even at >7mJ output energies

*HASS: Highly Accelerated Stress Screening

The integrated, one-box design employs the new STAR regenerative amplifier module for increased energy, beam quality and stability. This is seeded by Coherent's hands-free Vitara oscillator, and is powered by a new pump laser offering enhanced power overhead, stability and beam quality. The final, key sub-system is the proprietary, sealed stretcher / compressor designed for superb dispersion compensation and durability.

Mira OPO-X Fully Automated IR/Visible OPO

The new Mira OPO-X from Coherent is a synchronously pumped, widely tunable, optical parametric oscillator (OPO) accessory that dramatically extends the wavelength coverage of their fs and ps Ti:S lasers (such as Mira and Chameleon) from 505nm to 4000nm. It is fully automated providing software controlled tuning over the full specified wavelength range. This is made possible by its advanced control electronics, built-in diagnostics, and powerful control software package.

Mira OPO-X is designed around a unique fan-poled non-linear crystal technology. Rather than having a single fixed poling period in the OPO gain crystal matched to one pump wavelength, the crystal is poled in a fan geometry across the width of the crystal providing a continuously variable, quasiphase-matching period. This allows fully independent tunability between pump and OPO output wavelengths enabling two-colour applications such as simultaneous multiphoton excitation imaging of different fluorophores, uncaging, CARS/SRS and other two-colour pump-probe experiments.

For further information please contact:
Dr Dale Otten
Coherent Scientific
dale.otten@coherent.com.au

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Continuously Tunable Laser (CTL) available from Toptica

The CTL is the ultimate choice when looking for a laser that is widely tunable without any mode-hopping. It has high power, a narrow linewidth and high absolute and relative wavelength accuracy. Wide scans can be performed with highest resolution. With the fully digital, low noise and drift DLC pro controller, the CTL laser is easy to use and operate via touch-screen and knobs as well as via remote PC GUI and command language.

The new CTL lasers are ideally suited for applications that require large mode-hop free tuning ranges, such as the resonant excitation of small structures like quantum dots and micro-cavities. Also molecular spectroscopy and components testing will benefit from CTLs exceptional properties.

Specifications:

- Mode-hop-free tuning up to 110 nm
- Available at 950 nm, 1500 nm and 1550 nm
- Up to 80 mW output power
- High resolution and wavelength accuracy
- User friendly touch screen, buttons and remote control

Lastek appointed exclusive distributor for Zolix!

Zolix

Lastek are pleased to announce that Zolix of China, the largest manufacturer of optical spectrometers and specialist instruments, has appointed Lastek as their exclusive distributor for Australia and New Zealand.

Zolix manufactures single, double and triple monochromators and spectrographs up to 750mm focal length. They also offer a comprehensive range of light sources and detectors that can be coupled with their monochromators and spectrographs. Their product offering is the most comprehensive we have seen for optical spectroscopy.

UV Raman and UV resonance Raman are a Zolix speciality as the technique was developed by Chinese academic Can Li in China. He cooperates closely with Zolix and they have established a laboratory at Zolix's factory in Beijing to jointly develop applications and instruments for this technique.

For further details please contact Dr Zhen Fang Gong at Lastek, zhen@lastek.com.au. Zhen is visiting Zolix this month for product training.

Quantum Composers Synchronizers for Spectroscopy

Timing is a critical element in all spectroscopy applications. Properly coordinating the light source, detection instrument, and data collection method makes all the difference in obtaining high quality and repeatable results. Quantum Composers' digital pulse and delay generators provide extremely precise synchronization signals to meet the demands of any spectroscopy application, including Laser Induced Fluorescence spectroscopy (LIF), Trace Gas Spectroscopy, and Laser Induced Breakdown (LIB) Spectroscopy.

Pulse/Delay Generators for Spectroscopy:

We carry a wide range of pulse generators to fit the needs of any budget or application. Our pulse generators provide a cost-effective method to create and synchronize multiple sequences, delayed triggering, or any precisely timed series of events.

HySpex hyperspectral imaging cameras

Hyperspectral imaging, or imaging spectroscopy, combines the power of digital imaging and spectroscopy; for every pixel in an image, a hyperspectral camera acquires the light intensity (radiance) for a large number of contiguous spectral bands.

Every spatial pixel in the image contains a continuous spectrum (in radiance or reflectance), which can be used to characterize the objects in the scene with great precision and detail.

HySpex VNIR-1800

Utilizing a cutting edge actively cooled and stabilized scientific CMOS, the VNIR-1800 is ideal for high-end data acquisitions where high radiometric accuracy is required.

The dynamic range of 20 000 ensures outstanding SNR levels even in darker areas of the image of highly dynamic scenes. With a max frame rate of 260 fps, combined with aberration corrected optics and high optical throughput (f/2.5), HySpex VNIR-1800 offers a unique combination of data quality, high speed and sensitivity.

A wide range of close-up lenses allows the use of the camera at working distances ranging from a few cm with a spatial resolution of 24 μm, to infinity for e.g. airborne remote sensing.

HySpex SWIR-384

The new HySpex SWIR-384 hyperspectral camera from NEO, is developed for field, laboratory, airborne and industrial applications. The new state of the art MCT sensor with cooling down to 150K yields low background noise, high dynamic range and exceptional SNR levels.

With a max frame rate of 400 fps, combined with an aberration- corrected optical system with high optical throughput (f/2), the data quality, speed and sensitivity is truly state of the art.

A wide range of close-up lenses allows the use of the camera at working distances ranging from a few cm with a spatial resolution of 53 μm to infinity for e.g. airborne remote sensing.

HySpex ODIN-1024

HySpex ODIN-1024 is a next generation state-of the-art airborne hyperspectral imager, covering the spectral range from 400 to 2500 nm.

Perfect co-registration between 1024 spatial pixels for VNIR and SWIR is achieved by employing a novel common fore-optics design. Along with the extreme resolution, the unique design provides high sensitivity and low noise, low spatial and spectral miss-registration (smile and keystone).

With supreme data quality, HySpex ODIN-1024 includes real-time data processing functionalities such as real-time geo-referencing of acquired images. It also features a built-in on-board calibration system to monitor the stability of the instrument.

For more information please contact Raymax at info@raymax.com.au or 02 9979 7646

Renishaw launches the new inVia™ Qontor™ confocal Raman microscope

Warsash Scientific is pleased to announce Renishaw's most advanced Raman microscope, the new inVia Qontor. Building on the market-leading inVia Reflex, the inVia Qontor adds a new dimension to the performance and ease of use for which inVia is renowned.

The inVia Qontor sees the addition of Renishaw's latest innovation, **LiveTrack™ focus tracking technology**, which enables users to analyse samples with uneven, curved or rough surfaces. Optimum focus is maintained in real time during data collection and white light video viewing. This removes the need for time consuming manual focusing, pre-scanning or sample preparation. The inVia Qontor Raman microscope's cutting-edge technology reduces overall experiment times and makes analysing even the most complex samples easy.

Renishaw inVia Raman imaging microscopes offer the highest levels of flexibility, sensitivity and performance for applications ranging from materials, minerals & inorganics, polymers & pharmaceuticals, semiconductors & photovoltaics, paint and conservation science, inks, dyes, narcotics, explosives and other chemical criminalistics all non-contact and non-destructive.

Renishaw is a recognised leader in Raman spectroscopy and has a team of over 100 scientists and engineers specialising in the production of fully configurable Raman systems.

Warsash Scientific has over 22 years of sales and support across Australia and New Zealand with Renishaw Spectroscopy Products Group and is Australia's leading supplier of Raman spectroscopy solutions.

Ophir-Spiricon's NanoScan 2s Beam Profiler

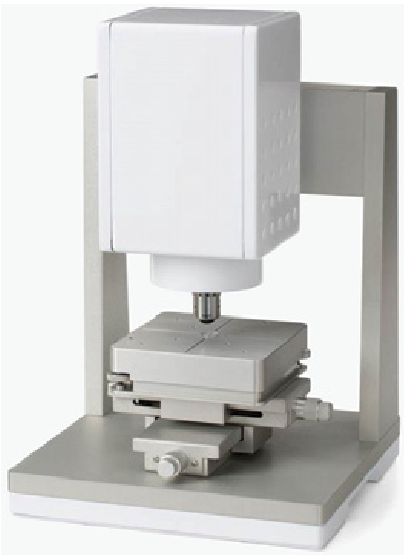
Warsash Scientific is pleased to announce the release of the latest version of NanoScan™2s scanning slit laser beam profiler **for sub-micron measurement of beam position and size** from Ophir-Spiricon, global leader in precision laser measurement equipment and a Newport Corporation company.

Now available in a more compact size, NanoScan 2s is a NIST-calibrated profiler that instantly measures beam position and size with sub-micron precision for CW and kilohertz pulsed lasers with measurement update rates to 20Hz. The profiler offers silicon, germanium, or pyroelectric detectors; this allows profiling lasers of any wavelength from UV to far infrared, to 100µm and beyond.

NanoScan 2s uses moving slits – one of the ISO standard scanning aperture techniques – to measure beam sizes from µm to cm at beam powers from µW to kW. The natural attenuation provided by the slit allows the measurement of many beams with little or no additional attenuation required. The digital controller provides deep, 16-bit digitization of the signal for high dynamic range up to 35dB power; this makes it possible to measure beam size and beam pointing with 3-sigma precision to several hundred nanometres. The silicon or germanium detector-based NanoScan 2s's include an integrated 200mW power meter that displays both total power and individual power in each of the beams being measured.

NanoScan 2s software can measure from one to 16 beams in the aperture with sub-micron precision. A beam can be found in less than 0.3 seconds and real-time updates can be displayed to 20Hz. The user can configure the display interface however it is desired; displaying only those results of most interest on one easy-to-read screen, or on multiple screens. The software controllable scan speed and a "peak-connect" algorithm allows the measurement of pulsed and pulse width modulated lasers with frequencies of 10kHz and higher. The NanoScan 2s software comes in two versions, STD or PRO. The Professional version includes ActiveX automation for integrating the profiler into OEM systems or creating custom user interface screens using C++, LabVIEW, Excel, or other software packages.

ProFilm 3D - 3D Optical Profilometer



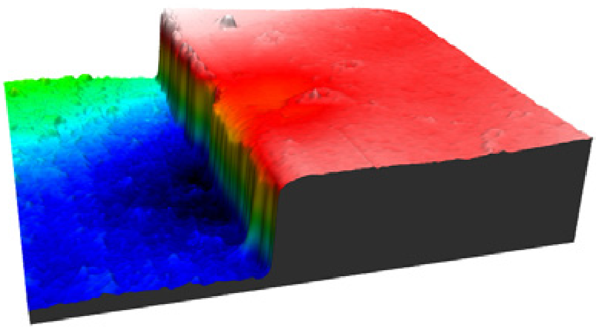
Warsash Scientific are pleased to announce the release of the ProFilm3D low-cost optical profiler from Filmetrics, leader in affordable thin film measurement solutions. www.filmetrics.com

The Profilm3D uses the state-of-the-art methods of vertical scanning interferometry and phase shifting interferometry to measure 3D surfaces with high accuracy. With these technologies, it is possible to measure surface features and roughness with sub-nanometre resolution.

Important measurements such as surface profiles, step heights, and roughness can be made optically for less than the cost of a stylus profilometer. This is especially important for users who want to measure metal thickness in seconds and with a single mouse click.

"The goal of Filmetrics with the Profilm3D is to substantially lower the entry barrier for high-accuracy profiler equipment, thus allowing more companies worldwide to profit from the use of this technology," says Scott Chalmers, CEO of Filmetrics. "It is the same approach we applied some years ago to thin-film measurement equipment, which made us the world's leader in that market."

Every Profilm3D comes equipped with intuitive step-height measurement and roughness measurement software. For more advanced data manipulation, Filmetrics offers a great deal on TrueMap, from our partners at TrueGage. Profilm3D data is, of course, also compatible with other industry-standard software analysis packages.



The Profilm3D's exceptionally wide field-of-view (2 mm with a 10x objective lens, 0.8µm resolution, 100mm x 100mm XY scan range, 37mm (500µm piezo) Z axis) - and its digital zoom helps alleviate the need for multiple objective lenses for different applications, thus further reducing the overall cost of ownership. For those applications where the flexibility of multiple objective lenses is still required, manual and automatic turrets are available.

Australia's Part in the Global Effort to Discover Gravitational Waves

by Paul Lasky and Letizia Sammut

This article was originally published on THE CONVERSATION

The historic discovery of gravitational waves announced in February involved the work of more than a thousand scientists working tirelessly in several different institutions, across many different countries and timezones.

LIGO Laboratory operates two detector sites, one near Hanford in eastern Washington, and another near Livingston, Louisiana. Each site has two detector arms that act as an interferometer on a large scale. This photo shows the Livingston detector site. Image credit: Caltech/MIT/LIGO Lab.

Why is an entire village, albeit a diverse and disparate one, required to verify experimentally the last of Einstein's major predictions in his theory of general relativity? And how does such a village function and coordinate in such a way that maximises scientific output?

A tour of the village

LIGO Scientific Collaboration consists of two individual experiments, located at two sites in the United States, separated by 3,000 kilometres. At each site, a single, very high-power laser beam is split in two, and travels down two perpendicular four kilometre-long vacuum tunnels.

At the ends of these tunnels the laser hits large, 40-kilogram mirrors suspended by an intricate series of pendula to reduce shaking from external forces.

The laser light returns along the same tunnel, and recombines. Gravitational waves cause the actual length of each arm to change. The way the laser light recombines is used to determine this change.

In order to make a detection, the LIGO instruments needed to measure a change in arm length equal to 1,000th the diameter of a proton. Performing such a measurement is a remarkable technological feat that involves development across multiple scientific streams.

These fields include, but are not limited to; quantum physics and quantum metrology; high-powered optics; mechanical systems including thermal and vibrational control systems; general relativity and gravitation; theoretical astrophysics and traditional astronomy; large-scale computing … the list goes on.

The multidisciplinary nature of this experiment is reflected in the structure of the LIGO Scientific Collaboration (LSC), which looks more like a corporate entity than a traditional scientific collaboration.

Among other things, there are many, many science working groups which fall within the scope of three main themes: instrument science, detector characterisation and data analysis.

Alongside the science working groups sit groups such as Education and Public Outreach, Diversity, and the Presentation and Publications Committee.

Each working group is a dynamic, scientific collaboration all unto themselves. Each has a chairperson, or multiple co-chairs, who report to the theme leaders who, in turn, report to the LSC spokesperson, executive committee and council.

Who works in the village?

So exactly how many scientists does it take to detect a gravitational wave? This particular effort took 1,006 scientists working tirelessly in 16 countries in 83 different institutions, located in 14 different timezones!

Research for the discovery was done all over North America, Brazil, throughout Europe, Russia, India, China and South-East Asia and Australia.

We, along with about 50 colleagues, work on this experiment in Australia. A majority of the leadership group work in institutes in the US, at places such as CalTech and MIT.

The result of this unfortunate circumstance is that full, collaboration-wide teleconferences typically take place between 2am and 4am in Australian time. Over the past few months, building to the announcement, this has affected our lives many times!

In general, science working groups hold weekly teleconferences. Many of us are part of working groups that only exist on two continents, making it possible to schedule meetings that also allow for a relatively normal existence.

Many of us also work in groups that have numerous members on three or more continents; very early, or very late teleconferences are not uncommon, but remind us of the scale of the collaboration and the international effect of our work.

What do they do?

As mentioned before, this is a precision measurement! Every aspect of the experiment is incredibly finely-tuned. For example, multiple groups and individuals around Australia work on the technology and design of the mirrors.

Monash University researcher Yuri Levin, while a PhD student of Kip Thorne's at CalTech, developed the theoretical framework for computing thermal noise (which is now widely used within the collaboration). From this work it became clear that LIGO mirrors require exceptionally high-quality reflective coatings.

The coating noise Levin anticipated is now considered to be among the most serious sources of noise in the LIGO experiment.

Scientists at Adelaide University developed, installed and commissioned wavefront sensors for the LIGO mirrors that measure the mirrors' change in shape due to the temperature of the high-powered laser, and corrects these

distortions.

Researchers at CSIRO developed mirror coatings and polishing techniques for the initial phase of the LIGO experiment that lasted from 2002 to 2010. A team at the Australian National University developed tip-tilt mirror suspension systems that can be used to steer the laser light with remarkable accuracy.

A group at the University of Western Australia have built a mini-LIGO experiment that is used, among other things, to study an instability the high-powered laser can induce on the mirrors, causing them to wobble uncontrollably.

Each element and each component of the incredibly complex LIGO system undergoes incredible levels of development and scrutiny.

This is perhaps best exemplified in the data analysis sphere. In Australia, we have strong groups at Monash University, the universities of Melbourne and Western Australia, the Australian National University and Charles Sturt University.

We all work on developing and running computer software that can pick a tiny signal out of noisy data streams. Somewhat infamously, LIGO puts itself through a process called blind injections.

Blind injections are performed by a very small group of people. The team inject a fake signal into the data stream by artificially shaking the mirrors of the detector in such a way that makes it looks like a gravitational wave has passed through.

The unsuspecting data analysts play their usual games of analysing this data and, lo and behold, inevitably find the signal.

An early result?

The most famous of these blind injections occurred in September 2010. Very soon after the signal was automatically injected into the detectors, it was picked up with the initial data analysis algorithms.

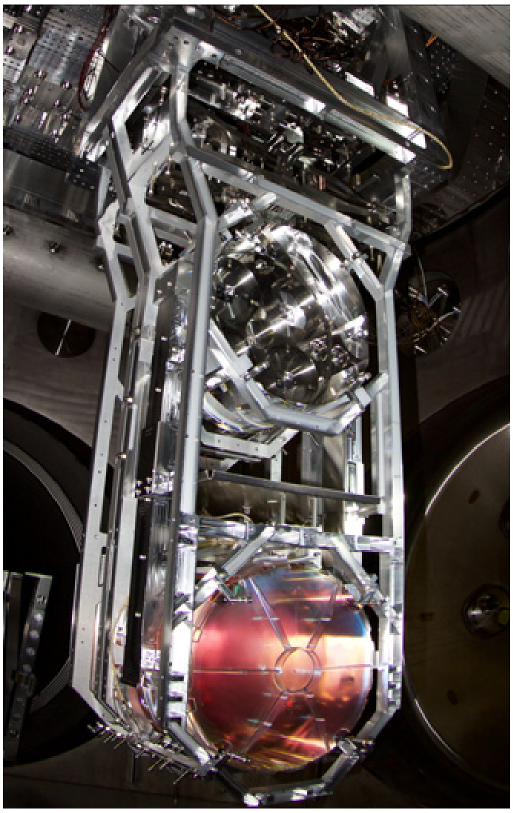
The purported signal looked like it came from the constellation Canis Major, and the event was subsequently called the "Big Dog". The collaboration then went through a six-month process of vetting, checking, and re-checking the analysis, and even wrote up a full paper to be submitted to the journal.

An independent Detection Committee reviewed all of the results, and a collaboration-wide vote was held on whether to submit the paper for peer review – the result was an anonymous "yes".

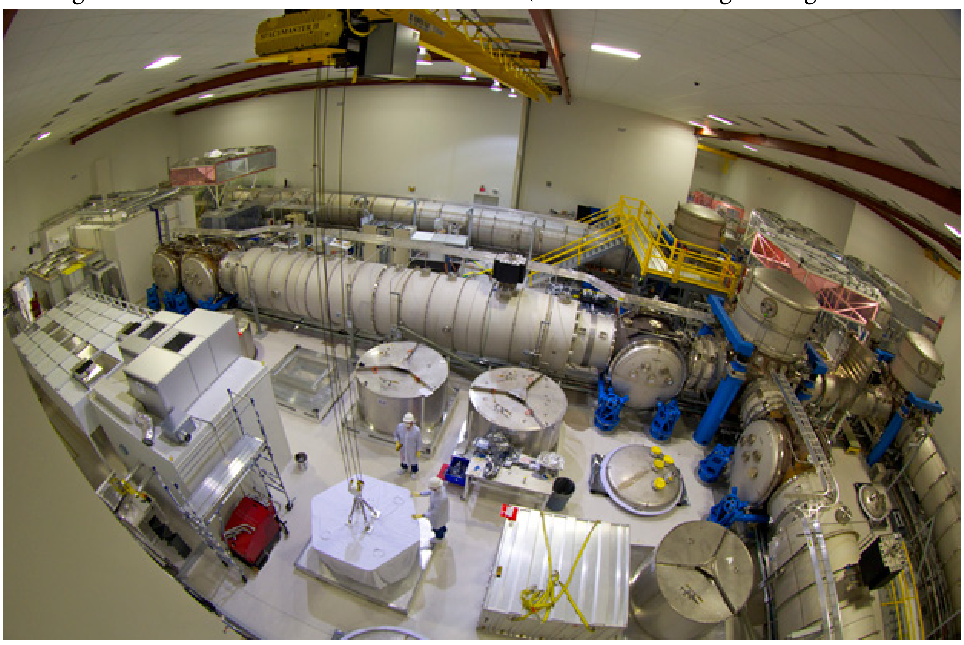
And then the envelope was opened: the signal was fake.

That exercise, while incredibly painful to many, shows just how seriously the LIGO Scientific Collaboration takes its science. That this latest detection was not a blind injection has been known by the entire collaboration for a long time – the experiment was only beginning to collect data, and the blind injection software had not yet been set up properly.

Less than one hour after the LIGO experiment wobbled from the gravitational wave on that fateful day on September 14, 2015, one of us (Lasky) and fellow Monash academic and LIGO researcher Eric Thrane, who sits on the fake injection committee, were sitting at our laptops at home when we both received an email titled "Very interesting event on ER8" (ER8 stands for Engineering Run 8, which was the name of the pre-science phase of the experiment).



The photo shows one of LIGO's test masses installed as the 4th element in a 4-element suspension system. Test masses are the mirrors that reflect the laser beams along the lengths of the detector arms. They're used to test changes in the interferometer's arm-lengths caused by the passage of gravitational waves. The 40 kg test mass is suspended below the metal mass above by 4 silica glass fibres. Image credit: Caltech/MIT/LIGO Lab.



The laser and vacuum equipment area (LVEA) at the corner station of the LIGO Hanford detector houses the pre-stabilised laser, beam splitter, input test masses, and other equipment. Image credit: Caltech/MIT/LIGO Lab.

A quick Skype conversation quickly ensued:

Thrane: Have you seen the email?

Lasky: Yes. Is it a false injection?

Thrane: No!

Lasky: Did we just detect a gravitational wave?

Thrane: I think we did.

And the rest, as they say, is history.

This is truly the dawn of a new age of discovery. The gravitational-wave universe has many untold stories to tell, and scientists across Australia are striving to tell the tale along with the rest of the world.

Paul Lasky and Letizia Sammut are Postdoctoral Fellows in Gravitational Wave Astrophysics, Monash University.

The original article can be found at theconversation.com/australias-part-in-the-global-effort-to-discover-gravitational-waves-54525

Graphene Oxide Films, an Emerging Platform for Ultrathin, Light-weight, Flexible Photonic Devices

by Xiaorui Zheng, Han Lin and Baohua Jia

Graphene and its derivatives have attracted unprecedented enthusiasm during the past decade due to their exceptional mechanical, thermal, optical, and electrical properties [1-3]. This article reviews recent research conducted at our laboratory on the optics and applications of graphene oxide (GO) and reduced graphene oxide (rGO) films.

Introduction

Graphene oxide (GO), the graphene sheet covalently decorated with various oxygen functional groups either on the basal plane or at the edge, is an attractive material due to a unique set of physical and chemical characteristics arising from the hybridisation of sp^2 and sp^3 carbon atoms. Moreover, the electronic and optical properties of GO can be tailored by manipulating the size, shape and relative fraction of sp^2-hybridised domains of GO during its reduction process [4].

The reduction of GO can be seen as the removal of the oxygen functional groups. Various strategies have been demonstrated to effectively reduce GO including thermal, chemical, and the more appealing laser reduction methods. Being free of the high temperature or toxic chemicals required in thermal or chemical reduction methods, laser reduction allows not only precise control of the reduction extent, but also localised manipulation of the properties of GO films. Most importantly, the flexible micro-structure patterning on GO ultrathin films can be realised simultaneously during the laser reduction process [5]. As a result, flexible and ultra-lightweight GO films with both controllable properties and predefined arbitrary structures can be readily achieved using one-step mask-free direct laser printing (DLP), enabling numerous optoelectronic and photonic applications [5].

Here we review the recent research conducted at our laboratory on the optics and applications of GO and reduced graphene oxide (rGO) films using the DLP method. Our results demonstrate the great potential of GO films as an emerging integratable platform for ultrathin, light-weight, flexible photonic devices.

Synthesis and reduction of graphene oxide

GO films can be synthesised via the vacuum filtration process, which involves the filtration of a GO suspension (Figure 1a) through an anodic aluminium oxide membrane. As liquid (water) passes through the membrane, the GO sheets are filtered on the membrane, forming high quality GO thin films. Then the GO thin films can be transferred onto various substrates (Figure 1b) by either dissolving the membrane or peeling off the film with the aid of water. Moreover, nanoscale control over the film thickness can be achieved by simply varying either the concentration of the GO solution or the filtration volume.

A femtosecond pulsed laser beam is focused onto the surface to reduce the GO film (Figure 1b) and arbitrary patterns (Figure 1c) can be implanted simultaneously following computer controlled 3D movement of a scanning stage. To harness the nonlinear photochemical mechanism and minimise thermal effects, the laser beam operates at 800 nm with a low repetition rate of 10 kHz, enabling sub-micrometre scale fabrication resolutions (Figure 1c). The atomic structure of GO can be seen as sp^2 carbon atoms decorated with various oxygen functional groups (Figure 1d). After absorbing photons during the laser reduction process, the oxygen groups can be either partially or fully removed (Figure 1d), resulting in not only the tuneable physical properties of rGO but also flexible patterning capabilities. As shown in Figure 1c, a contrast between rGO (dark areas) and GO (light brown areas) can be clearly identified under an optical microscope, indicating the modified optical properties of rGO film reduced via the DLP method.

Linear optical properties of graphene oxide

The response of materials to external electromagnetic fields is fundamental information required for designing various

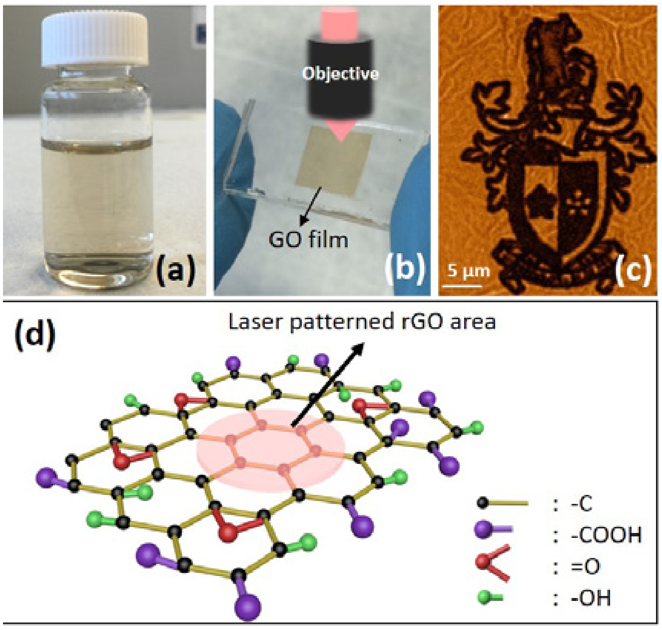


Figure 1. (a) GO flakes in water solution. (b) A GO film transferred onto the polydimethylsiloxane flexible substrate after vacuum filtration. A focused laser beam used to reduce the GO film is also shown schematically. (c) The optical microscopic image of an arbitrary pattern (Swinburne logo) generated on the GO film during laser reduction via the DLP method. Scale bar: 5 μm. (d) The atomic structures of GO and rGO after laser reduction.

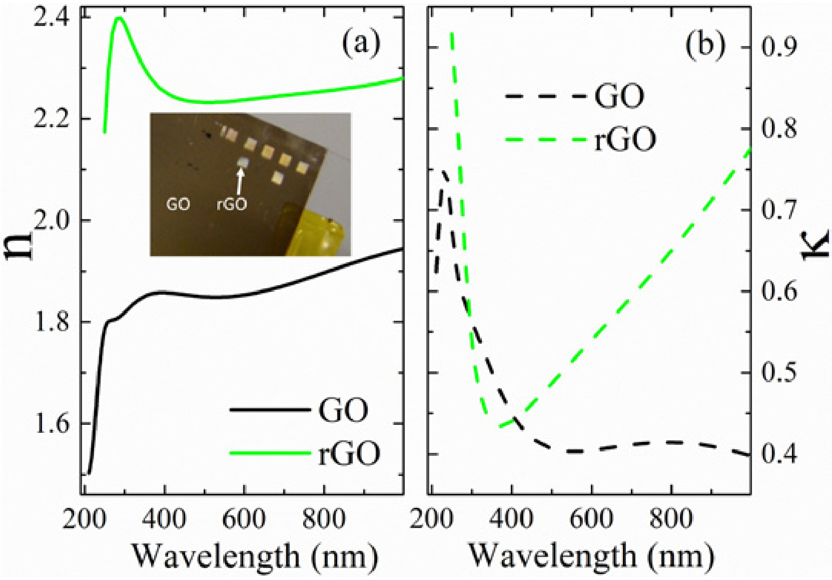


Figure 2. (a) The dispersion relations of refractive index of GO and rGO films. Inset: The GO film with various rGO areas patterned by the DLP method. (b) The dispersion relations of extinction coefficients of GO and rGO films.

optical components for different optical applications. Compared to the extensively investigated electrical properties, the optical properties of GO or rGO films are less explored. The optical properties of GO and rGO films are highly sensitive to the oxygen functional groups in terms of the type, fraction and their distributions on the basal plane. This increases the complexity involved in understanding the fundamental physical properties of these films and hinders useful device design. In our laboratory, the linear optical properties of GO and laser-induced rGO films have been investigated [6]. In particular, their broadband linear dispersion relations from the ultraviolet (UV) to near-infrared (NIR) regions have been characterised using spectroscopic ellipsometry (SE).

The linear dispersion relations of GO and laser-induced rGO films at different reduction extents (inset of Figure 2a) were studied experimentally using the SE method. Figure 2 shows the dispersion relations of GO and rGO films with the highest reduction extent from 200 nm to 1000 nm after fitting the SE data. GO film shows an almost dispersionless refractive index (n) of 1.9 above 400 nm, which further proves the broadband optical property of GO film. However, the refractive index of GO film decreases immediately in the UV range, which is due to abnormal dispersion from the strong absorption of GO film in that range. On the other hand, the extinction coefficient (κ) of GO film keeps as low as 0.4 above 400 nm and increases obviously in the UV range, which is consistent with the refractive index behaviours. The dispersion relation of the rGO film with the largest reduction extent shows a similar trend compared to that of the GO film. However, both the n and κ values are found to increase and the absorption peak redshifts compared to that of the GO film, which is consistent with the ultraviolet-visible spectra of GO and rGO films [7]. As a result, the fitted high accuracy dispersion relations of both GO and laser-induced rGO films have not only validated the fitting model, but also shed some light on laser reduction mechanisms compared to the more widely used thermal and chemical reduction methods.

It has been reported that the optical constants of multilayer graphene are smaller than that of bulk graphite due to a possible decrease in interlayer interaction for a small number of layers [8-9]. Also the increase of n and κ values for the multi-layer thermally reduced GO stack is greater than the increase found in the case of thermally treated single or few layer (but still thin) GO sheets [10]. Moreover, it has been reported that the thickness of rGO films upon laser patterning reduces obviously [5]. As a result, it can be envisioned that the effect of laser reduction is to remove interlamellar water, which leads to the increase of refractive index. On the other hand, the significant increase of the extinction coefficient is due to the removal of the oxygen functional groups and the reduction of the optical bandgap of the GO layers [10].

Nonlinear optical properties of graphene oxide film

In addition to linear optical properties, optical nonlinearities are of great importance for high performance all-optical photonic devices. In particular, nonlinear optical absorption has been proved useful for a number of applications including optical limiting to protect sensitive instruments from laser-induced damage, and saturable absorption for pulse compression, mode-locking and Q-switching. On the other hand, nonlinear refraction (Kerr effect) is crucial for functionalities including all-optical switching, signal regeneration and fast optical communications. However, research on nonlinearities of GO is largely limited to the nonlinear absorption of GO solutions. The nonlinear activities during the process of laser-induced reduction from GO to rGO films have remained unexplored, which are the key to realising the functionality in the patterned GO integratable optoelectronic devices.

Firstly, we investigated the in-situ nonlinear activities of GO films during their entire laser-induced reduction process through continuous increase of the laser irradiance until optical

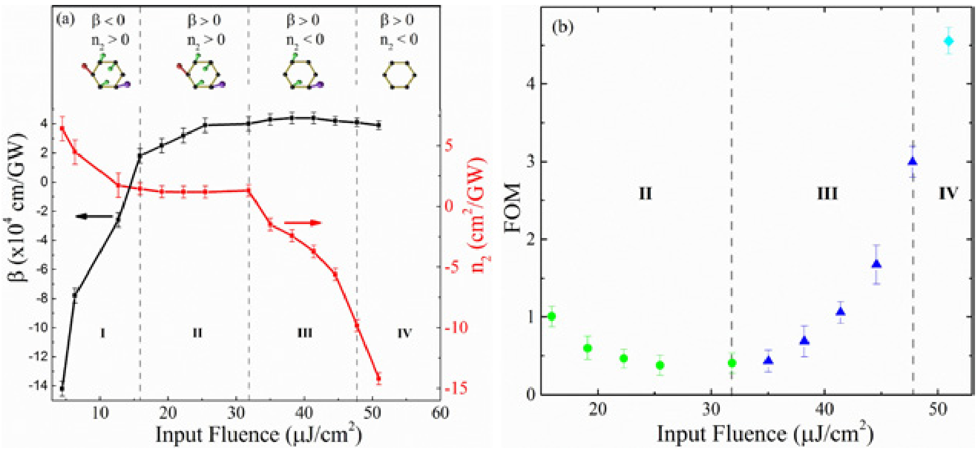


Figure 3. (a) Plot of nonlinear refractive index n_2 and nonlinear absorption coefficient β versus the input laser fluence. Nonlinear activities as well as atomic structure of GO film in the four different stages (I, II, III, IV) are summarised. (b) Nonlinear FOM in Stages II, III and IV.

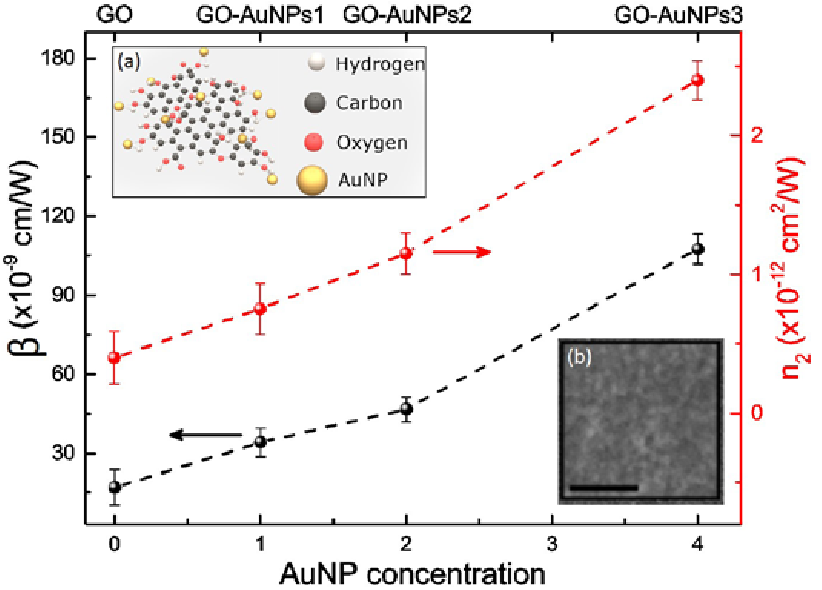


Figure 4. Nonlinear absorption coefficient and nonlinear refractive index of GO and hybrid GO-AuNPs films with increased AuNPs concentrations (GO-AuNPs1, GO-AuNPs2 and GO-AuNPs3), deduced by fitting the open aperture and close aperture Z-scan curves. Inset (a). Schematic illustration of the hybrid GO-AuNP films. Inset (b). SEM images of the GO-AuNPs film. Scale bar: 500 nm.

breakdown [11]. As shown in Figure 3, four stages of different nonlinear activities have been discovered with increased laser irradiance. Both the tuning of the nonlinear absorption response and a switch of the sign for the nonlinear refractive index are observed during the transition from GO to rGO. Meanwhile, the giant Kerr nonlinear responses are observed to be three orders of magnitude larger than those in the previous reports [12], leading to a giant nonlinear figure of merit (FOM) crucial for functional nonlinear device design (Figure 3b). Various nonlinear mechanisms are responsible for the observed nonlinear activities including ground-state bleaching of the sp^2 domain, two-photon absorption and excited state absorption of the sp^3 matrix, and population redistribution [11]. Our results have not only explored the rich nonlinear responses of GO films during its reduction to rGO films, but also demonstrated the tunability of nonlinear properties, in particular n_2, of GO films for highly integrated nonlinear photonic applications on a thin film.

In order to further enhance the optical nonlinearity of GO, we demonstrate a flexible method to functionalise highly transparent GO film with gold nanoparticles (AuNPs) through the vacuum filtration process [13]. The effective functionalisation of GO films with AuNPs (insets of Figure 4) has been revealed by both spectroscopy and scanning electron microscopy (SEM). Both the nonlinear absorption and refraction of low-loss hybrid GO-AuNP films are found to be enhanced monotonically with the increase of AuNP concentration by the Z-scan measurement, as shown in Figure 4. The enhanced nonlinear light-matter interactions of the hybrid GO-AuNP films can be attributed to efficient energy and/or charge (electron) transfer upon photoexcitation, and synergistic coupling effects between AuNPs and GO. Our hybrid GO-AuNP films would provide a solid-state material platform for diverse nonlinear optical applications, such as ultra-sensitive optical limiter, optical modulator and photodetector. Moreover, the vacuum filtration method can serve as a universal strategy to functionalise GO by easily doping various nanoparticles with tuneable concentrations to manipulate the physical properties of hybrid GO materials.

Flexible optical devices on ultrathin graphene oxide films

Given the linear and nonlinear optical properties of GO and rGO, it is now convenient to propose and realise various ultrathin flat optical devices on GO and rGO films by fully exploring the flexible patterning capabilities of DLP on the GO film as well as the controlled optical properties during its laser-induced reduction process. Recently we have successfully demonstrated an ultrathin GO lens and an ultrathin GO polariser, indicating its great application potentials in next-generation on-chip photonic systems [14-15].

I: Ultrathin graphene oxide lens

Tremendous efforts have been devoted to developing ultrathin flat lenses, such as micro Fresnel lenses and conventional micro lenses, plasmonic lenses and metalenses [16-17]. However, it is still challenging to have ultrathin optical lenses with 3D subwavelength focusing resolution, high focusing efficiency, broadband operation, ultra light weight, low-cost manufacturing and flexible integration capability. Therefore, we propose a new ultrathin flat lens concept based on the effective manipulation of the phase and amplitude of an incident light beam simultaneously.

As shown in Figure 5a, the GO flat lens is made possible by the sub-micrometre

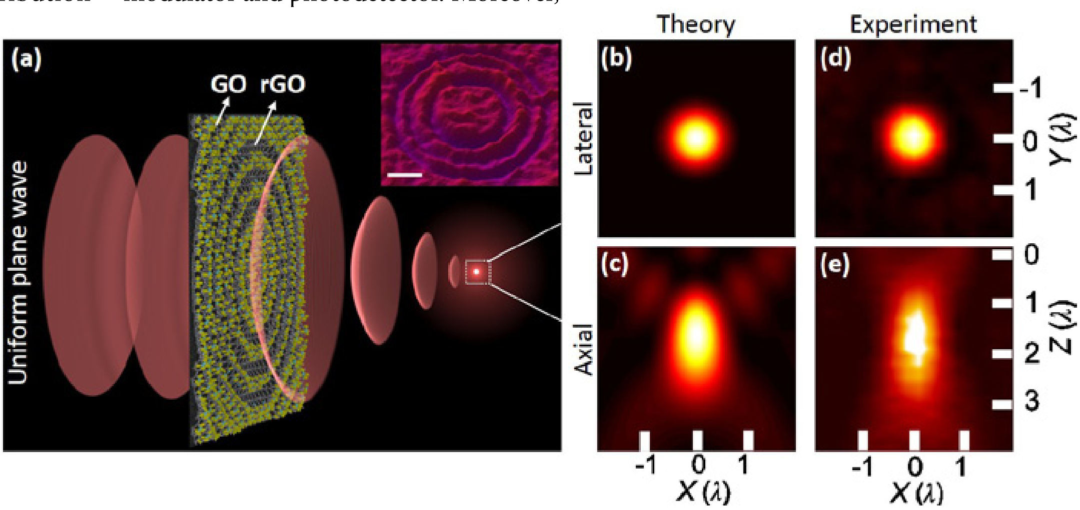


Figure 5. (a). Schematic figure of wavefront manipulation by the GO lens converting the incident plane wave into a spherical wavefront. Inset: optical profiler image of the GO lens. Scale bar: 2 μm. (b,c) Theoretical focal intensity distributions in the lateral and axial directions. (d,e) Experimental focal intensity distributions along the lateral and axial directions.

concentric ring fabrication in a GO film using the mask-free DLP method to convert the GO into rGO via the photoreduction process. The laser power controllable removal of the oxygen functional groups in the exposed regions of the GO film leads to three continuously tuneable local physical property variations: the reduction of film thickness, the increase of refractive index and the decrease of transmission/increase of extinction coefficient. When a uniform plane wave impinges on the GO lens, part of the beam is absorbed and refracted by the rGO zones, experiencing substantial amplitude as well as phase modulations. The other part of the beam propagating through the GO zones only experiences negligible amplitude modulations. As a result, a subwavelength 3D focal spot can be realised due to the interference of wavelets originating in the lens plane from different zones, which has been confirmed by its cross-sectional plots in the lateral and axial directions both theoretically and experimentally (Figures 5b-e).

We demonstrate a 200 nm-thick GO flat lens with 3D subwavelength focusing that is able to tightly focus broadband light from visible to near-infrared (~1100 nm bandwidth) with an averaged absolute focusing efficiency of >32% over the entire band. Our flexible GO lenses are mechanically robust and maintain excellent focusing properties under high stress. The simple and scalable fabrication approach enables wide potential applications in on-chip nanophotonics. The new wavefront shaping concept with laser patterned GO ultrathin films, provides new and viable solutions for ultra-lightweight, highly efficient, highly integratable, flexible optical systems, opening up new avenues for various multidisciplinary applications including non-invasive 3D biomedical imaging, laser tweezing, all-optical broadband photonic chips, light harvesting, aerospace photonics, optical microelectromechanical systems and lab-on-a-chip devices.

II: Ultrathin graphene oxide polariser

Ultrathin polarisers have been extensively studied both theoretically and experimentally including metamaterials, metasurfaces, wire-grid polarisers and guided resonance-based polarisers, as the indispensable elements in integrated optical systems [18-20]. However, the extinction ratio and the efficiency of the polarisers are greatly restricted by considerable metallic losses, in particular in the shorter wavelength ranges for wire-grid polarisers. Also, the operation wavelength of guided resonance-based polarisers is greatly limited to 1550 nm due to conventional available transparent materials in the infrared range such as silicon and indium phosphide. Moreover, time consuming and cost-ineffective manufacturing methods are required for both fabrication and deposition of conventional materials such as silicon or metals. As a result, it is still challenging to realise ultrathin polarisers from the visible to the infrared ranges with high extinction ratio, high transmission efficiency, flexible and integratable capabilities and cost-effective manufacturing methods.

Inspired by the wonderful optical properties of GO and laser-induced rGO films, an ultrathin micro-polariser on GO film has been proposed. The periodic 2D C-shape array on the GO thin film (left inset of Figure 6) has been designed and transmission spectra have been calculated for both TM and TE polarisations, respectively, as shown in Figure 6. Clearly the asymmetric Fano resonances can be observed for both polarisations, corresponding to the indirect transmission process where the incident energy excites the guided resonances [21]. Also the direct transmission process has been confirmed by the Febry-Perot oscillation of the background. Moreover, by introducing asymmetric structures (C-shape in our case), the spectra are highly sensitive to the incident polarisation. For example, a high transmission as large as 0.8 for TE polarisation can be observed at ~ 1.3 μm, whereas almost zero transmission is shown at the same wavelength for the TM polarisation due to the strong confinement of the incident light within the PC slab (right inset of Figure 6). As a result, the observed strong polarisation sensitivity of the guided resonance on our GO thin film can potentially serve as an ultrathin planer polariser.

By carefully designing the GO film thickness and C-shape geometry, a linear ultrathin micro-polariser with high extinction ratio (>3000), one order of magnitude larger than the current guided resonance-based polarisers [20], has been achieved. Also the thickness of the GO thin film is optimised at 100 nm not only to support guided resonances, but also to reduce linear absorptions. As a result, efficiency as large as 80% of the ultrathin GO polariser has been achieved, suppressing the metallic wire-grid or metasurface polarisers [18-19]. The working wavelength can be tuned over a broadband range from the visible (600 nm) to the NIR (1.6 μm) ranges due to the dispersionless nature of GO, largely extending the current working wavelength range (1.5 μm) using silicon or indium phosphide materials. In addition, the incident-angle (θ in the left inset of

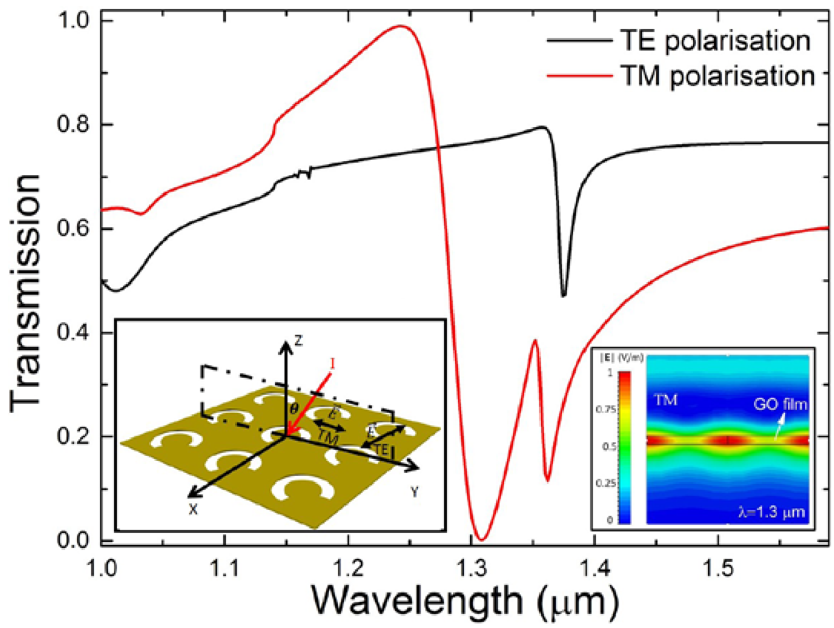


Figure 6. The transmission spectra of the proposed GO polariser with TE and TM polarised light incidence. Left inset: The schematic design of the proposed GO polariser with 2D periodic C-shape arrays. The C-shape array is in the x-y plane and the incident light is in the y-z plane with the colatitude angle θ. Right inset: the strong confinement of the incident light within the GO polariser under TM polarisation.

Figure 6) dependence of the micro-polariser has been investigated and high extinction ratio remains for a wide range of incident angles as large as 30°. It should also be emphasised that the proposed ultrathin GO polariser can be readily fabricated using one-step mask-free DLP, offering flexible and cost-effective manufacturing capabilities. Therefore, our GO micro-polariser may provide various on-chip photonic applications due to its high efficiency, broadband working wavelength range, large extinction ratio and cost-effective manufacturing.

Conclusions

In summary, the fundamental optical properties of GO and rGO films after DLP, and their applications in optical devices have been investigated in our laboratory. A wide range of topics have been covered including various experimental and theoretical approaches, the understanding of the optical responses, and the design and optimisation of GO optical devices. GO films show unique properties that are unavailable to conventional materials such as tuneable linear and nonlinear optical properties, a versatile patterning capability by DLP, surface functionalisation possibility, wavefront shaping ability, and mechanical robustness, which are highly demanded for the next generation of ultra-lightweight, highly efficient, highly integratable, and flexible optical systems, opening up new avenues for various multidisciplinary applications.

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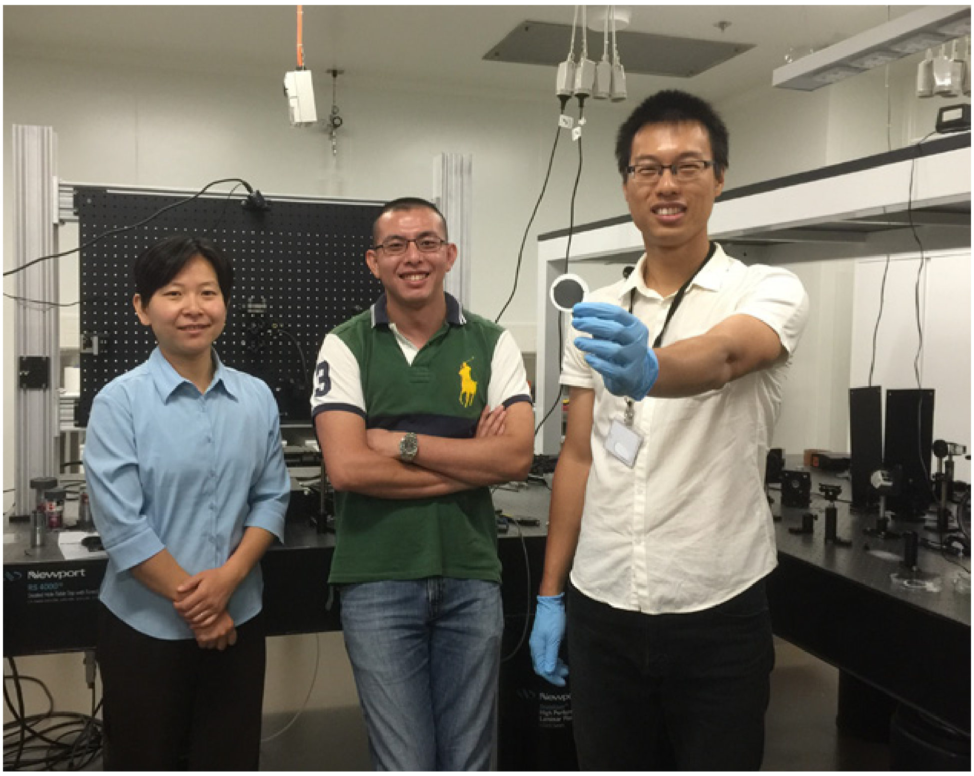

Figure 7. Team members from the Centre for Micro-Photonics at Swinburne University of Technology involved in this work. Left to right: Baohua Jia, Han Lin and Xiaorui Zheng. Xiaorui is holding a flexible GO film.

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Optics in Everyday Life: Periscopes

by Tony Klein

Once when my kids were young, a little bird decided to build its nest and lay its eggs just outside a garden window, on a small sapling visible from inside the house. Rather than let the girls stand on a chair inside the window, I mounted an inclined mirror overlooking the nest and showed the kids how to hold another mirror at eye level to form a crude periscope for viewing the nest.

There is rather more to periscopes, as I am about to show, but basically two mirrors or 90° prisms in a Z configuration form the basics, for seeing over trench parapets or avoiding bullets aimed at the visors of tanks. For more advanced versions, a terrestrial telescope is incorporated between the two right-angled prisms, containing an objective lens and an eyepiece, in addition to inverting prisms as shown in Figure 1.

More sophisticated versions, used for scanning the horizon by rotating the upper mirror, incorporate a Dove prism which, through mechanical gearing, is made to rotate at half speed[1] and an Amici prism between the objective lens and the eyepiece to revert the inverted image. This configuration, shown in Figure 2, is used for example in armored cars.

The main problem that becomes immediately obvious in such simple periscopes is the field of view. The upper mirror defines the entrance aperture, and it is viewed through the exit aperture that in practice is the eyepiece. Only a small range of incident angles of light reach the eyepiece – the rest are lost on the inside wall of the tube that contains the lenses, prisms and mirrors. How can this restricted range of angles be increased, i.e. how can a larger field of view be admitted?

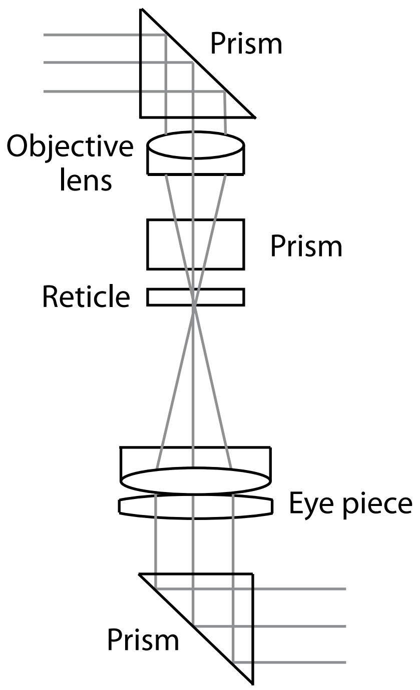

Figure 1. Periscope incorporating a terrestrial telescope.

The standard solution of this problem in terrestrial telescopes and other optical instruments is simply to insert intermediate lenses, called field lenses, located in such a way that they produce images of the entrance aperture in intermediate planes between the objective and the eyepiece. In this way, any ray that enters the entrance aperture will find its way into exit aperture where the eyepiece is located, as shown in Figure 3. In this way, not only the light but also the image is transported along the tube, via the intermediate images, which are found in the planes of the intermediate field lenses.

Such an arrangement, called a relay train is absolutely mandatory in the best-known application of periscopes, namely the ones used in submarines. Here, the length of the tube containing the light path can be several meters long, i.e. many tens of times longer than the diameter of the tube containing the lenses. In this situation, were it not for a series of intermediate relay lenses inserted between the lenses that carry the light between the entrance aperture and the exit aperture (i.e. the eyepiece), all one could see would be a small hole at the end of a long tube. These intermediate lenses will then transport the image between entrance and exit. A simplified schematic of a submarine periscope is shown in Figure 4.

So this is the main principle that makes periscopes rather subtler than just a pair of mirrors.

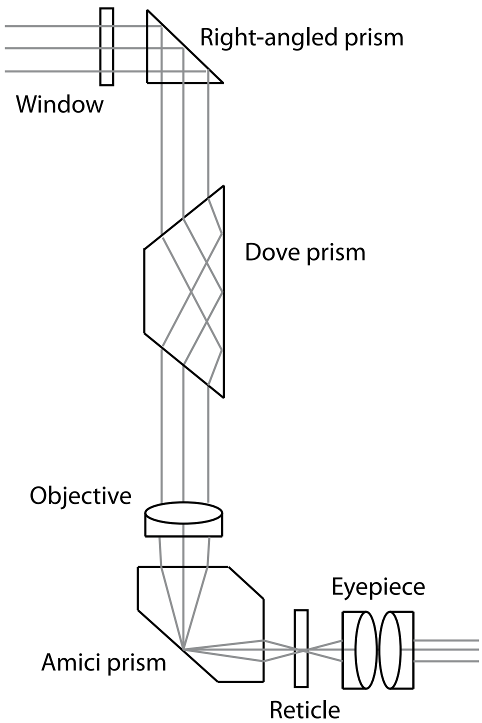

Figure 2. Tank periscope with erect image, for scanning the horizon[2].

An even more extreme class of situations in which not just light but images are to be transported, is where only very narrow paths are available, such as in endoscopes for looking into the insides of machinery or for medical applications. In earlier times, short, articulated tubes containing mirrors and lenses, in other words flexible sections of periscope were used, for example in gastroscopes, arthroscopes etc.

However in more recent times they were replaced when optical fibres took over, in coherent bundles in which individual thin fibres, carrying one pixel each, connect corresponding points in the entrance and exit planes. But in even more modern applications, tiny video cameras, connected electronically, with any sized monitors, make life even easier for applications such as keyhole surgery.

More modern endoscopes and periscopes can therefore utilise miniaturised high-resolution video cameras, equipped with wide-angle and zoom lenses. Thus, instead of trains of relay lenses or coherent fibre bundles image transport is done serially, with radio-frequency electronics or photonics. I wouldn't mind betting that in modern submarines the classic periscope is

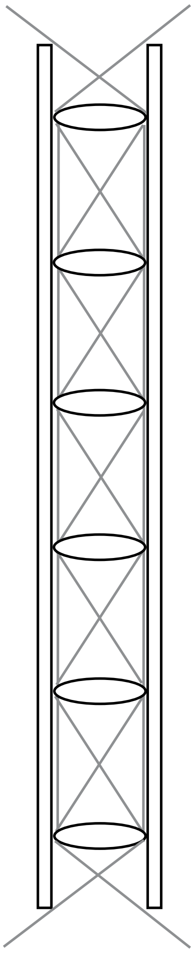

Figure 3. Periscope relay train with field lenses.

actually being replaced by a digital camera on the end of a retractable mast.

Notes

[1] Exercise for the reader: convince yourself that the image through a Dove prism rotates at double speed when the prism rotates.

[2] During World War II, when Australia was cut off from military supplies from Great Britain, a major project centred on the University of Melbourne came into being in order to manufacture "optical munitions". With optical quality glass produced by the School of Chemistry, the School of Physics successfully manufactured prisms and lenses for just this type of instrument, under the leadership of Professor Thomas Laby.

Emeritus Professor Tony Klein is a Foundation Member and Past President of the AOS. Tony is with the School of Physics, University of Melbourne.

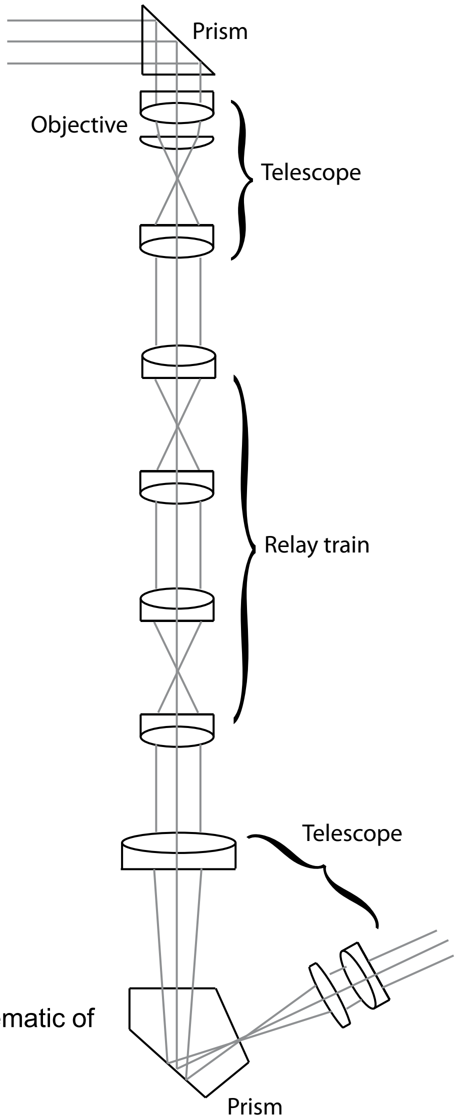

Figure 4. Simplified schematic of a submarine periscope.

Conferences

11-15 July 2016 NUSOD

The 16th International Conference on Numerical Simulation of Optoelectronic Devices will be held in Sydney from 11 to 15 July at the Sydney Nanoscience Hub, University of Sydney. Formed in 2001, NUSOD has become an established international meeting with a specific aim to bring together both theorists and experimentalists to study the most interesting problems in the field of photonics. Academic researchers, device engineers and software developers are invited to discuss the advancement and exchange of practical use of numerical tools at the cutting edge of photonics research and device design.

Registration deadline 31 May 2016 nusod.org/2016

5-8 September 2016 BGPP, NP and ACOFT

The Bragg Gratings, Photosensitivity and Poling in Glass Waveguides (BGPP), Nonlinear Photonics (NP) and Australian Conference on Optical Fibre Technology (ACOFT) will be held in Sydney from Monday 5 to Thursday 8 September 2016 in conjunction with the OSA. BGPP addresses all aspects of grating structures, photosensitivity, glass relaxation and poling in optical fibre and waveguides from physical fundamentals, properties and fabrication approaches to applications. The Nonlinear Photonics meeting is a venue for researchers interested in all aspects of nonlinear optical processes in structures, devices and systems. ACOFT addresses all aspects of guided wave optics including the theory, materials, technologies and applications associated with waveguide devices and integrated photonics.

Abstracts due 3 May 2016 osa.org/en-us/meetings/optics_and_photonics_congresses/photonics_and_fiber_technology

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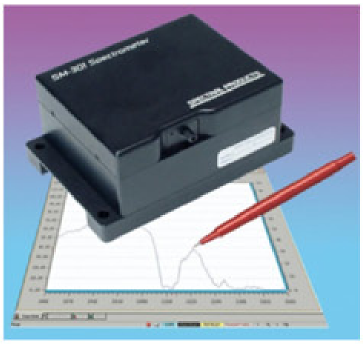

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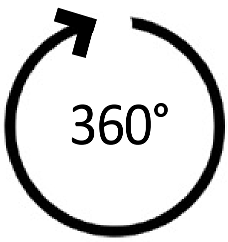

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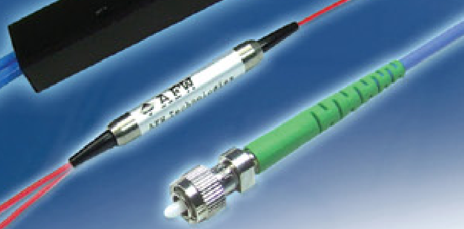

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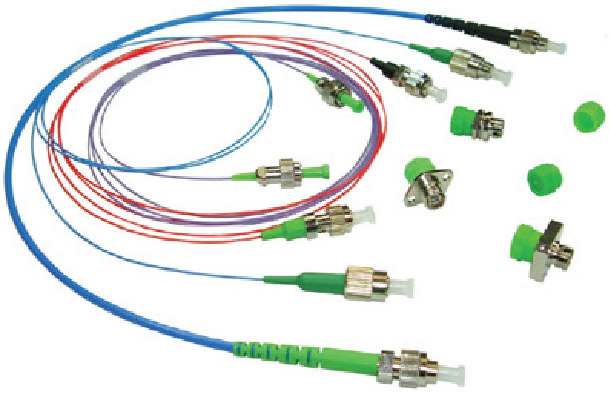

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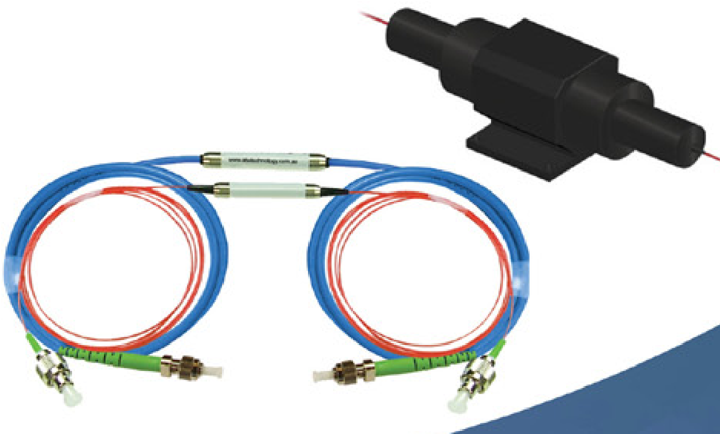

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