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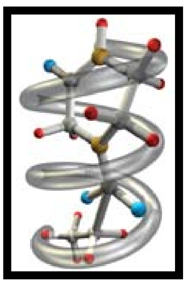
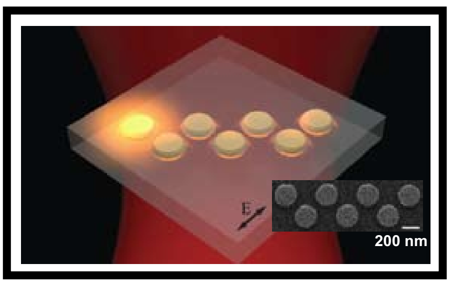
AUSTRALIAN OPTICAL SOCIETY





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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.

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  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.

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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Potential advertisers in AOS News are welcomed, and should contact the editor.
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Copy Deadline
Articles for the next issue (December 2015) should be with the editor no later than 13 November 2015, advertising deadline 6 November 2015.

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AOS News is the official news magazine of the Australian Optical Society. The views expressed in AOS News do not necessarily represent the policies of the Australian Optical Society.

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October 2015 Volume 29 Number 3

Articles

Departments

Cover Pictures:

- View of UNA during the stargazing world record attempt in Canberra as part of IYL and Science Week activities. UNA is a sculpture at the ANU science precinct that is designed to represent stars visible to the naked eye. Artwork and images that showcase light have been a major aspect of the Year of Light campaign as they help build a connection with the general public, see page 16. Image credit: Jim Zhang.
- Insets (left to right)
  - Oxopiperazine is a chiral molecule, see page 28.
  - An illustration of a zigzag array of gold nanodiscs, with SEM image inset, see page 12.

AUSTRALIAN OPTICAL SOCIETY

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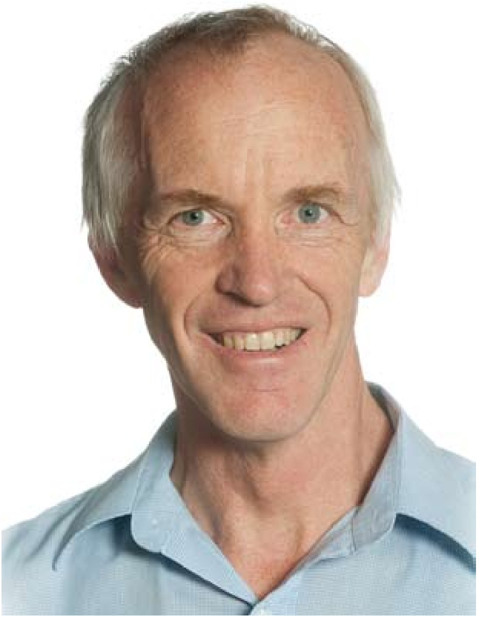
President's Report



At this time I am pleased to announce the AOS prizes for 2015. Warm congratulations to Professor Joss Bland-Hawthorn for being awarded the W.H. Beattie Steel Medal, Marcus Doherty for being the Geoff Opat Early Career Researcher award winner, and Katie Chong who is the AOS Postgraduate Student Prize winner. The prize recipients are scheduled to receive their awards at our annual conference (see below). Please remember that applications for the 2016 awards, including the Technical Optics Award, are due in early 2016. I also congratulate last year's W.H. Beattie Steel Medal winner, Tanya Monro and the 'Super Dots' team, for winning the UNSW Eureka Prize for Excellence in Interdisciplinary Scientific Research for developing nanocrystals to detect hidden, diseased cells within the body.

Since my last column a wide variety of IYL 2015 activities have taken place. In Melbourne, Science in Public organised a terrific set of short presentations for the "Light in winter" program at Federation Square late one Sunday afternoon in June. Tony Klein, a past-president of AOS has provided an overview of these presentations for this edition of AOS News; around 100 people attended. A few days later on Friday 19 June, there was the opportunity to learn about light pollution in a fireside chat called "Reclaiming the Stars", which featured Tanya Hill (Melbourne Planetarium), Nick Lomb (Powerhouse Museum) and Therésa Jones (University of Melbourne). It was a clear night in Melbourne and a decent coat was definitely needed despite the warmth emanating from the fire! The first two speakers discussed how artificial light interferes with astronomy and reduces our ability to observe the stars about us, whilst the final speaker described how the different spectral qualities of modern lighting are affecting the behaviour of various animals. More recently, National Science Week provided further outreach opportunities, including attempts at the stargazing world record (the ABC reported that on a field at ANU amateur and professional astronomers braved cold weather to help set the world record for the most people stargazing simultaneously in one place - officially 1,869 people, surpassing the previous record of 649 by more than 1,000 people)! Whilst it's hard to see how effective our various activities have been, it's clear that the community is taking advantage of modern developments in lighting technology; e.g. across the road from Federation Square, St Paul's Cathedral recently converted all of it's lighting to LEDs. As I noted previously, AOS Council is well aware of the need for IYL2015 to have a lasting impact and, to this end, is considering the development of an updated "roadmap" for optics and photonics in Australia; your ideas are welcome! Last time I touched the current efforts of the Chief Scientist to highlight the role of STEM (i.e. Science, Technology, Engineering and Maths) for our economy, including the need for encouraging secondary students into these fields of study. Clearly this is having an effect as the issue was mentioned in the ABC television series "Utopia"!

At the present time our colleagues in Adelaide are busy organising the annual meeting of AOS, under the banner ANZCOP 2015, or the Australian and New Zealand Conference on Optics and Photonics 2015. The venue is the University of Adelaide and it will run from Sunday 29 November to Thursday 3 December. ANZCOP 2015 integrates two longstanding conference series, the Australian Conference on Optics, Lasers and Spectroscopy (ACOLS) and the Australian Conference on Optical Fibre Technology (ACOFT). The conference is suitably timed to include the AGM for AOS. We will be delighted to welcome the President-elects of our international partner societies, Alan Wilner representing OSA and Bob Lieberman representing SPIE.

Looking ahead to 2016 AOS will be offering two conferences: the BGPP (Bragg Gratings, Photosensitivity and Poling in Glass Waveguides), NP (Nonlinear Photonics) and ACOFT meeting has been confirmed for 5-8 September in Sydney and will be run in partnership with the OSA, whilst for 4 -8 December, the 22nd Australian Institute of Physics Congress will be held in conjunction with the 13th Conference of the Association of Asia-Pacific Physics Societies in Brisbane. As 2016 marks the centenary of the birth of Aleksandr Prokhorov in the Atherton Tablelands region (in far north Queensland) and one of the co-winners of the 1964 Nobel Prize in Physics for the invention of the laser (see my article in the March issue of AOS News) it is hoped to organise events to highlight the laser (like LaserFest in 2010).

Stephen Collins
AOS president

Editor’s Intro

Welcome to another issue of AOS News. We have a great range of articles, with details of some of the International Year of Light events that have taken place in the past few months as well as articles on subwavelength topological photonics, superchiral light and smartphone spectroscopy. Other items in this issue include an article about AOS Foundation Member and Past President, Parameswaran ‘Hari’ Harihahan, who passed away in late July and our ‘Optics in Everyday Life’ section, which looks at Australia’s participation in the development of optical fibres. I hope you enjoy reading them all. As usual, please let me know if you have any suggestions for anything you would like to see in AOS News or have any articles or other items you would like to submit.

The International Year of Light is drawing to a close, with the many events reaching a number of people to give them some inspiration and understanding of light and its uses. There has been a wide range of activities, with everything from art displays, photo competitions, public lectures and forums, to mass participation events. Science week was a great showcase of optical technology and science with fantastic events all over the country. Hopefully this has managed to engage people about science and light and given them an idea of the impact optics has on their lives.

A recent article in the New York Times looked at the issue of low female participation in technology fields, with a mention of minority participation in science subjects as well. There were some very interesting aspects that were raised in the article, citing a study that was aimed specifically at student enrolment in computer science. It went on to say that when female students felt they did not ‘fit in’ they were less likely to choose computer science courses. Many of the issues are the same across all the sciences, but in physics we do have the issue of people having strong stereotypical views of what a physicist is like and that they don’t see themselves in that. Also there is the issue of inclusiveness in our physics departments and making sure everyone feels welcome. There are some great departments around with many role models of senior figures who break these stereotypes. There are also places where not everyone feels welcome or that they fit in. Some suggestions from the study mentioned in the article were to emphasise general interests and ‘normal’ behaviour of physicists as this really helped people when choosing a course. Also to ensure people have a better idea of what a physicist actually is rather than keep to their stereotypes, so that they can see themselves being interested in physics.

There are always multiple factors that contribute to an issue and various ways to try and address it. The National Science Foundation in the US released a report in February looking at evidence based strategies to increase diversity in STEM, proposing a number of suggestions, mostly based initially at the student level: financial support, social support, mentoring, research experience, combating stereotypes and building communities. They aim to increase participation in STEM from underrepresented groups such as women and minorities. After people from these groups choose a STEM pathway there is still the problem of retention. The report identified a gap particularly at the Early Career Researcher stage where there is a larger loss of females who continue on to post-doc positions after their initial training. The ultimate goal of the NSF is to have STEM participation rates that mirror the population. Having a clear pathway for early to mid-career researchers would help with this as this is one of the areas where the largest attrition occurs amongst minority groups compared to the overall average.

Identification of some of these issues is a good place to start in trying to address them, and having larger bodies involved in the process is a way to try and ensure real progress and change can occur. In September the Science in Australia Gender Equality (SAGE) pilot of the Athena SWAN Charter was launched to try and address underrepresentation of women in STEM. The charter has been running in the UK for ten years and is hoping to help to improve gender equity in Australian STEM organisations. 32 universities, research institutes and government research agencies are participating in the pilot scheme, where they will collect and analyse data on gender equity policies and practices in STEM departments and look at areas where things can be improved. It is a great step to show that organisations are interested in this issue and trying to do something about it. The hope is that in making things fairer it will improve life for everyone.

I hope you enjoy this issue of AOS News.

Jessica Kvansakul
Editor

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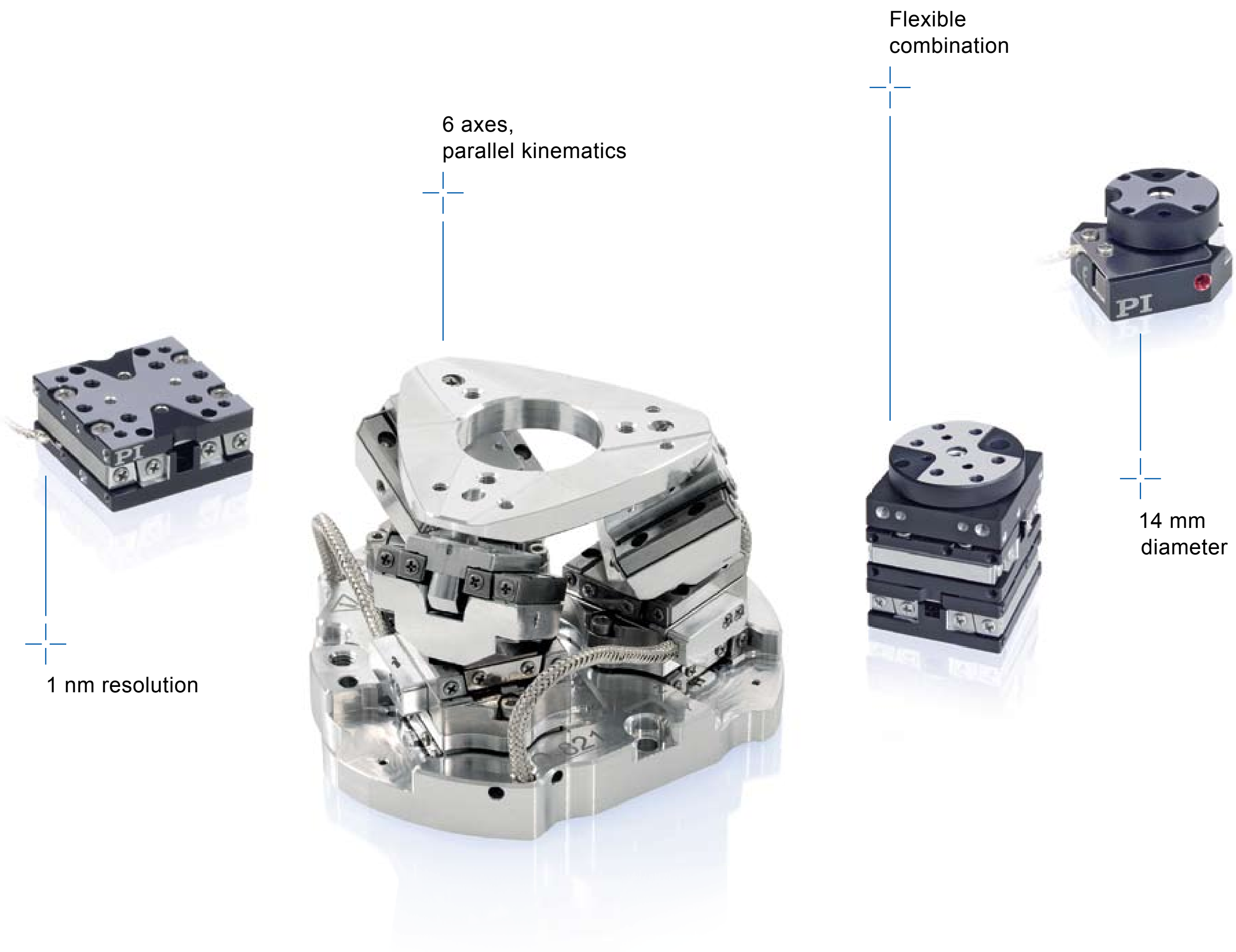

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MOTION | POSITIONING

The Light Revolution - IYL Public Forum in Melbourne

by Tony Klein

All photos taken by Megan Girdler/Science in Public.

To celebrate the International Year of Light, a public forum entitled The Light Revolution was held in Melbourne on the afternoon of Sunday, 14 June. Sponsored by the AOS and partner organisations this well-attended event was held in the Deakin Edge Theatre, Federation Square.

Ably compered by Ms Tanya Ha of the organisation “Science in Public”, the Forum was introduced by AOS President, Professor Stephen Collins who is a member of the Victorian Committee for the International Year of Light (IYL) in Australia. He explained how and why the IYL came about and how it is being celebrated in Australia and all around the world.

Next up was Dr Scott Watkins a former CSIRO scientist who is now an international business development manager. He spoke about LEDs and how they are changing the world. Resplendent in a T-shirt emblazoned with actively scintillating coloured LEDs, he started by explaining how LEDs work, what makes them so efficient and why the invention of the blue LED was worthy of a Nobel Prize. His main point was about the ways in which LEDs are transforming homes and cities and how the energy that they save will end up saving the world, giving as an example a project upon which he worked in India. Scott’s excellent talk led smoothly into the next speaker’s topic about combatting light poverty.

This was given by Shane Thatcher, CEO of “Illumination” - an Australian company that produces high quality solar products. He spoke about the over 1.2 billion people in the world who don’t have access to electric light and have to burn toxic and dangerous kerosene to light their homes - much like our forebears had to. All this can change by bringing safe, efficient and cost-effective solar-powered devices such as the “Mandarin Ultra” solar device that Shane invented and that his company manufactures and exports. He demonstrated the device, talked about its development, and outlined how Australian buyers for camping and similar uses, subsidise the export of the devices to third world countries.

The next speaker was Professor Andrew Holmes from the Bio21 Institute of the University of Melbourne, who is the current President of the Australian Academy of Science and a Fellow of the Royal Society. Andrew’s internationally acclaimed work is on conducting polymers - plastic materials that can conduct electricity and can be turned into devices that convert light into electricity and vice-versa. Indeed, the title of his talk was “Seeing the light with plastics”.

Dr Scott Watkins wore a T-shirt containing an LED display whilst presenting at the forum.

He found, in collaboration with a Cambridge University team of Physicists, that certain organic semiconductor polymers, sandwiched between transparent electrodes, can be made to give out light when hooked up to a battery, more or less like LEDs made from inorganic semiconductors like Gallium Arsenide. Not only that, but the process can be turned around and produce electricity when illuminated - i.e. like solar cells. Although not yet as efficient as silicon solar cells, the “plastic” devices are much cheaper to produce and indeed can be printed on A4 sized sheets and in long, continuous rolls.

Furthermore, it is possible to print a transparent surface with red, green and blue dots (pixels), producing a flat screen TV. The real challenge is to print large area solar cells, so “watch this

Shane Thatcher (Left) and Professor Andrew Holmes.

Professor Andrew Holmes spoke about his work on conducting polymers and "seeing the light with plastics". He is pointing at a sign made from polymer LEDs.

space"! As if to prove the point, Andrew Holmes then rolled out a red (-ish) roll of printed experimental solar cells, to form a red carpet for the last speaker for the afternoon's Forum.

Before that, however, Tanya Ha told the audience about another application of light. In a spectacular development at Monash University, along with collaborators from CSIRO and Deakin University, their spin-out company "Amaero" has succeeded in using 3-dimensional laser printers as metal prototyping machines to produce objects such as jet engines!

The last speaker was Professor James Whisstock, the director of another impressive and innovative facility at Monash University - the ARC Centre of Excellence for Advanced Molecular Imaging. His title was: Lighting up life: the new microscopy. He talked briefly about the deceptively simple $2 droplet lens that can turn a smartphone into a pathology lab, with the same resolution as a $10k lab microscope. However his main topic was a quite different sort of light, a million times brighter than the sun, namely that produced by the Synchrotron. The x-rays produced by a beam of electrons whizzing around the football-field-sized machine, when scattered from biological specimens, allow molecular biologists unprecedented insights into things such as the mechanisms of immunity, in examples like hayfever, rheumatism and auto-immune diseases.

Professor James Whisstock spoke about synchrotrons, Free Electron Lasers and their use in molecular imaging.

Other devices, such as X-ray producing Free Electron Lasers (XFELS) produce x-ray pulses a billion times brighter even than synchrotrons. These pulses destroy the specimens on which they are incident - but not before they allow the capture of images before the atoms have time to move. It is interesting to note that the development of this most recent type of "microscope", has in its vanguard several Melbourne-trained physicists.

This brought to an end a fascinating and wide-ranging program, aimed at giving the general public a glimpse into the most recent developments in the science of light (in its various forms) and the whole world of brilliant new applications.

Science in Public partnered with Federation Square and The Light in Winter Festival was responsible for organising this excellent and worthwhile Public Forum.

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

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INSPIRED WORK

Subwavelength Topological Photonics

by A Poddubny, A Slobozhanyuk, A Miroshnichenko, and Y Kivshar

Topological properties play a fundamental role in many physical phenomena. One example is the recently discovered novel state of matter called topological insulators [1].

These unique materials can be characterised by a new organisational principle known as a topological order. In solids an "ordinary" insulator does not conduct an electric current due to the absence of free carriers. Although a "topological" insulator still does not support current flow in the bulk, it always has a conducting surface due to the presence of edge states, which can carry current without dissipation even in the presence of impurities.

Recently there has been a burst of interest in exploring topological orders with photons. It has led to the discovery of new classes of photonic states of matter, such as *photonic topological insulators* [2]. Such systems allow us to emulate condensed matter systems in a simple and controllable way. Emulating numerous and exciting manifestations of topologically nontrivial systems such as, for example, spin-polarised transport and the quantum spin Hall effect, would also be highly desirable for many applications in modern nanophotonics. In particular, topologically protected electromagnetic states could be used for transporting photons without any losses or scattering in photonic crystals. More importantly, such states could be used to isolate antennas and other light sources or scattering objects from each other. Several intriguing theoretical schemes have been proposed to explore topological orders in electromagnetic systems, both in linear and strongly interacting regimes, but up to now experimental demonstrations and practical implementations have been very limited.

We recently suggested the first realisation of subwavelength topological states at the nanoscale [3]. We revealed that hybridisation of the polarisation-degenerate modes of the zigzag chains of plasmonic nanoparticles engenders the chiral-symmetric energy spectrum. The structure exhibits a topological transition, when the chain changes from a line to a zigzag (Fig. 1a). Namely, the straight chain spectrum is topologically trivial; it has a vanishing parity of the winding number **P**. For the zigzag chain this Z_2 topological invariant is nonzero (Fig. 1b) being the hallmark of edge states at both chain edges [3,4].

Our proof-of-concept experiment has confirmed the presence of edge states in the zigzag chain of gold nanodiscs in the visible [5]. The chain (Fig. 1c) was excited from the substrate side and the near field patterns of the plasmonic modes induced in the structure were mapped by a near-field scanning optical microscope. The near field has hot spots at the chain edges that can be switched by rotating the incident light polarisation (Fig. 1d).

Later, we extended our approach to a broader class of electromagnetic structures including dielectric nanoparticles with different symmetries of the coupled optical modes [4]. We observed subwavelength topological edge states for electric and magnetic dipole and magnetic quadrupole modes (Figs. 1e,f). Moreover, we demonstrated directly the robustness of the edge states against a disorder [4]. These results open the novel possibility of employing plasmonic and dielectric nanoparticles to engineer the subwavelength topological states of light.

Subwavelength topological edge states of light can be used for the creation of robust and noise-free photonic circuits for efficient optical data communication.

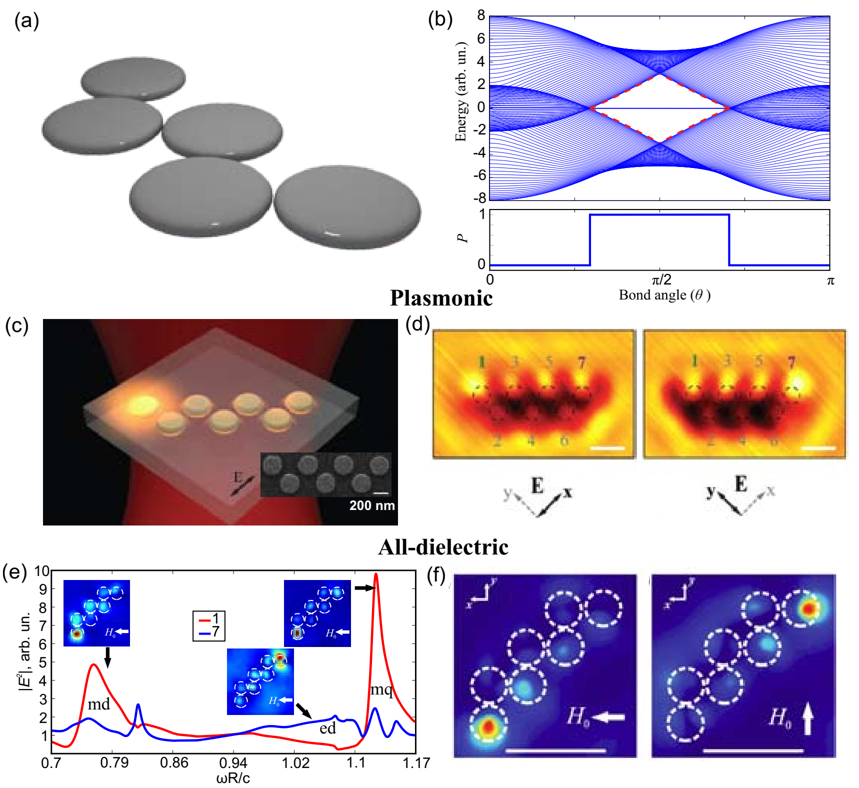

Figure 1. (a) Artist's view of a zigzag array of nanoparticles [3]. (b) Energy spectrum (above) and parity of the winding number (below) of the zigzag chain calculated as a function of the angle between three consecutive particles [4]. (c) Schematic illustration of the experimental setup together with the SEM image of the fabricated zigzag chain of gold nanodiscs [5]. (d) Near field map measured for two orthogonal polarisations of incident wave [5]. (e) Spectral dependence of the intensity of the electric field near the first and last dielectric spheres. The insets correspond to the electric field at the different resonances of the single particle [4]. (f) Experimental near field maps of the edge states excited in the chain of dielectric particles [4].

Furthermore, they open a number of possibilities ranging from nanoscale light sources, enhanced imaging, highly efficient nanoantennas or even quantum computing, and they could be used as entangled qubits for quantum computing.

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News - 2015 UNSW Eureka prize for Excellence in Interdisciplinary Scientific Research

AOS member Tanya Monro was part of a team who were awarded the 2015 UNSW Eureka Prize for Excellence in Interdisciplinary Scientific Research for their work on developing fluorescing nanocrystals to detect diseased cells in the body. The Super Dots team is led by Professor Dayong Jin from the University of Technology Sydney and Macquarie University, Professor Tanya Monro from the University of South Australia and University of Adelaide and Professor Bradley Walsh from Minomic International and Macquarie University. The work is continuing as part of the ARC Centre of Excellence for Nanoscale BioPhotonics.

The Super Dots team has developed nanocrystals that can find a diseased cell in a blood or urine sample with the aim of giving accurate non-invasive early diagnosis of prostate cancer. Cancer starts with a single cell, which can't currently be detected at the earliest stage. The Super Dot nanocrystals can be tested on a body fluid sample to detect cancer molecules and have been developed over the last two years to refine sensitivity for prostate cancer, so that they work to detect only small amounts of diseased cells at earlier stages than currently possible. The team hope that a prostate cancer test will be available within two years using these Super Dots.

Professor Bradley Walsh and Professor Dayong Jin collecting the 'University of New South Wales Eureka Prize for Excellence in Interdisciplinary Scientific Research' at the Australian Museum Eureka Prizes 2015 at Sydney Town Hall on August 26, 2015. (Photo credit: Brendon Thorne/Getty Images).

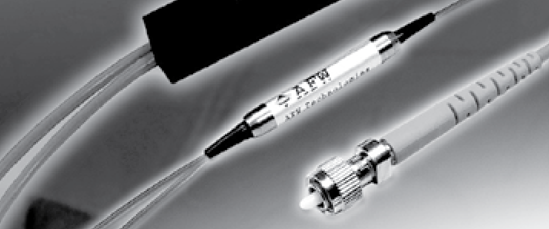
The project aims to be a platform technology that the team hope can be customised to detect other cancers as well as different applications. One of these is fast, accurate infection detection in children. A small blood sample could be tested with multiple nanocrystals coded to look for a number of specific pathogens, saving hours and reducing the amount of blood needed from patients to perform testing. Super Dots should be able to detect even a single molecule of infection as they are highly sensitive.

The team hope that the nanocrystals can also be implanted in the body and then can detect hidden, diseased cells by fluorescing on contact with them. As well as real-time diagnosis of disease, the technology has potential for creating invisible, lifetime-coded inks that could add 'uncrackable' security to banknotes and passports.

"By combining physics, chemistry and biology, this research should ultimately allow us to watch the interaction between drugs and cancerous cells at a molecular level within the patient's body," Kim McKay AO, Executive Director and CEO of the Australian Museum said.

Established in 1827, the Australian Museum is the nation's first museum and one of its foremost scientific research, educational and cultural institutions. The Australian Museum Eureka Prizes are the most comprehensive national science awards, honouring excellence in Research and Innovation, Leadership, Science Communication and Journalism, and School Science

See more at: http://australianmuseum.net.au/media/2015-eureka-interdisciplinary-scientific-research#sthash.s0edQXeF.dpuf



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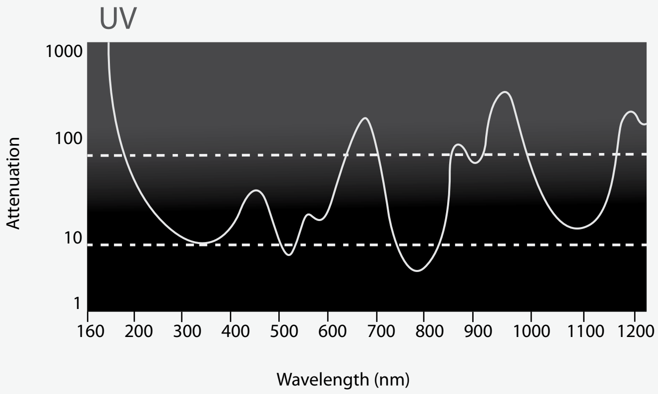

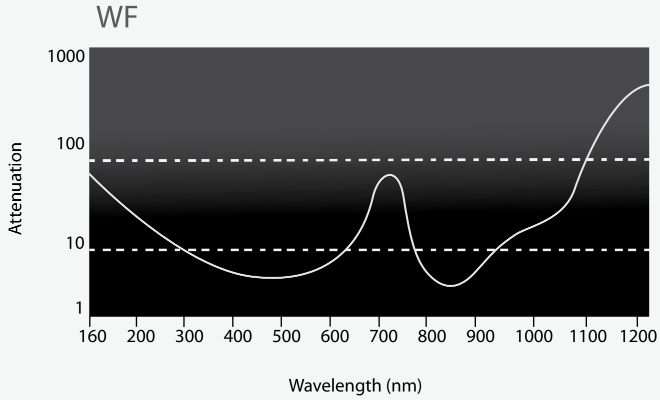

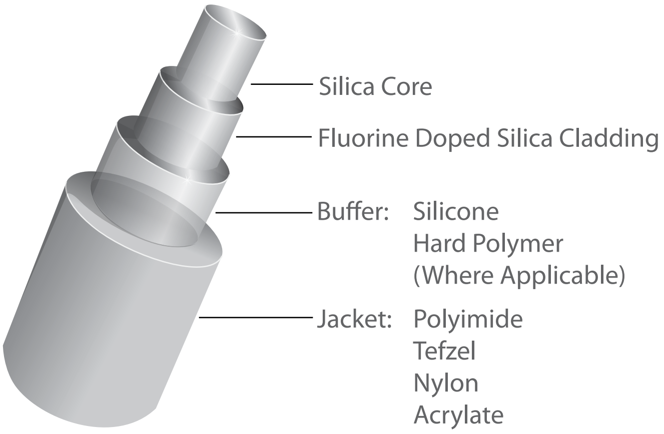

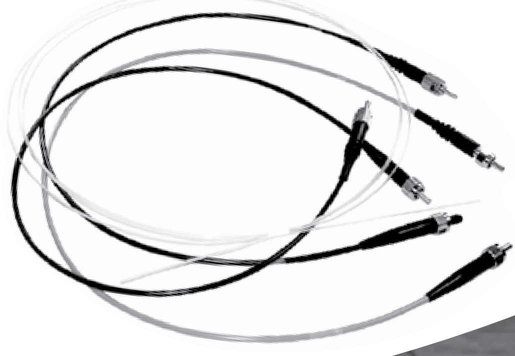

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Parameswaran ("Hari") Hariharan (1926 – 2015)

by Chris Walsh and Bob Oreb

Dr P Hariharan, known universally to his professional colleagues as Hari, passed away on 26th July of this year aged 88. His impact on Australian and international optics was profound, especially in the fields of interferometry and holography.

Hari in 2004. Photo courtesy of Iswar Hariharan.

Hari came to Australia in 1973 to join the research staff at what became the CSIRO Division of Applied Physics. He had a strong background in classical optics through positions at the Indian National Physical Laboratory (1949-51), the National Research Council (1951-54), and as Senior Professor at the Indian Institute of Science (IISc), Bangalore (1971-73). As Director of the laboratories at Hindustan Photo Films, Ootacamund (1961-71) he became an expert in photographic emulsions, which combined with his optical expertise gave him a background perfectly suited to the technically and artistically demanding field of holography.

Hari's early contributions included the design of a new three-beam interferometer, the double-passed Fabry-Perot interferometer, and the first practical radial-shear interferometer. This background in interferometry led naturally to his interest in holography. His expertise in processing photographic emulsions (the principal recording medium for the highest quality holograms) led to innovations that dramatically improved the diffraction efficiency and brightness of holograms as well as their stability. The artistic community was quick to recognise the value of his work; he collaborated with artists including Paula Dawson (http://www.pauladawson.com/), Alexander (http://www.art-alexander.com/), and Margaret Benyon (http://holowiki.nss.rpi.edu/wiki/Margaret_Benyon).

Along with his deep knowledge of classical optics, Hari was an innovative cross-disciplinary thinker. He recognised very early the power of modern electronics and microprocessors in optics, and in 1981 with colleagues at CSIRO developed a novel holographic exposure control system which combined the power of modern electronics and clever opto-mechanical devices to enable efficient and accurate holograms to be recorded every time. It was in interferometry, however, where this cross linking bore the best fruit. The principles of phase shifting interferometry were in their early stages of development, and Hari worked with Bob Oreb and Nick Brown at CSIRO to develop the hardware needed to shift the phase of the interferometer and the CCD-based detection to record the intensity patterns used by the phase-recovery algorithms. Concurrently with this experimental work, Hari developed more sophisticated algorithms that were less susceptible to phase shift errors and capable of greater accuracy in phase measurement.

The optical workshop at CSIRO Applied Physics was at that time manufacturing optical surfaces whose deviation from form (flat or spherical) was so small that quantitative measurement was increasingly difficult. Hari's innovations in digital interferometry were perfectly timed; with the principle of "if you can measure it you can make it" the interferometers designed and built by Hari and by Oreb allowed Leistner and his optical co-workers to produce optical components and assemblies that in subsequent years found their way into the LIGO interferometer, NASA instruments, optical solar observatories and into industry as reference optics for commercial interferometers.

Hari retired from CSIRO in 1991 as Chief Research Scientist, the Organisation's highest scientific rank. He continued his association with optics, working as an Honorary Fellow at Sydney University where he collaborated with Colin Sheppard's group. His research output, always prolific, hardly slowed in this 'retirement' phase of his life. His interests broadened as well: during this period he was the first to demonstrate achromatic phase shifting using the geometric phase, and made significant contributions to the study of quantum effects in optical interference.

Hari published more than 200 journal articles, wrote four highly-regarded books and five major reviews, as well as book chapters and optics articles for non-peer reviewed publications. One of his US collaborators visited him for a three month sabbatical; when she told him she was hoping to publish two or three papers with him he gave a wide smile and said 'I think we can do a little better than that' - and they did. For a more detailed list of Hari's publications go to the following Google Scholar page link: https://scholar.google.com/citations?user=ZxI6kRUAAAAJ&hl=en

As a colleague, Hari was unfailingly polite, thoughtful, and always willing to share his knowledge. If any of his colleagues had a problem in optics, a half hour spent with Hari was the best way to start down the road to solving it. His presentations were exemplars of clarity: the depth was always appropriate to the level of the audience, the coverage perfect, and the timing precise to the second. As a conference speaker he was a Chairman's dream. His books are much the same: concise and clearly written, with not an

irrelevant or unnecessary equation to be found. He had an ageless quality to him. Those of us who worked with him for twenty years never noticed a change in his personal appearance, his demeanour, or in his scientific insight.

Hari had a close association with the AOS. He is a past President of the Society and was awarded the AOS Medal in 1996. Through his close links to the International Commission for Optics (as a vice-President and Treasurer) and SPIE (Director) he played a major role in bringing the AOS closer to its international peer communities.

Hari's awards are too numerous to mention, but possibly those that meant much to him personally were the Gold Medal of SPIE in 2001, SPIE Dennis Gabor Award in 1992, and the Joseph Fraunhofer Award from the OSA in 1989.

In the latter years of his life Hari moved to the US to be closer to his children and grandchildren. He remarked to one of his CSIRO colleagues that life was 'rocking the grandchildren to sleep, over to the desk to write a paper, back to the grandchildren'. He passed away surrounded by his family, productive to the last.

IYL News - IYL World Record Attempt

The Mt Stromlo observatory-led stargazing record attempts on Friday 21 August during National Science Week as part of the Year of Light in Australia were a huge success. Guinness World Records confirmed 1869 stargazers at the attempt for the most stargazers at a single site at ANU, breaking the previous record of 649. For the record attempts stargazers observed the sky together for 10 minutes and could use a telescope, binoculars or camera with a telephoto lens to do so. The evening at ANU also included public lectures by a range of speakers including Nobel Laureate Professor Brian Schmidt, and was a great affair enjoyed by all.

The team hope that the attempt for the most stargazers at multiple sites across a country was also broken with the official numbers for this awaiting confirmation from Guinness World Records. The current record is held by Mexico with 3006 participants in 2013. The unofficial count across Australia was 8366 people at 38 sites, but this still needs official confirmation. More than 10,000 people registered to take part in the event with the entire stock of telescopes ordered by the organisers selling out before the combined events. The evening was well attended all over the country and fulfilled the goal of inspiring people about science and light, fitting perfectly as a Science Week and Year of Light event.

Participants were all asked to view the sky for 10 minutes to complete the record attempt. Photo credit: Jim Zhang.

A photo of UNA taken at the event. UNA is a stainless steel sculpture at the ANU science precinct by international artist Wolfgang Butress. It has perforations representing southern hemisphere stars visible to the naked eye, with the size dependent on the star's luminosity. Photo credit: Jim Zhang.

International Year of Light 2015

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Optics in Everyday Life: Optical Fibres - A Piece of History

by Tony Klein

There was a time, in the early 1970's, when Australia led the world with the best optical fibres for information transmission, meaning the ones with least attenuation over long distances.

Transparent dielectric tubes for carrying light have, of course, been known for a very long time but in 1966 physicists in the UK proposed their use, in the form of optical fibres, for the transmission of enormous amounts of information riding on streams of photons, rather than electrons. However the snag was that even the purest forms of glass or silica available at that time would scatter and absorb the photons leading to unacceptably high signal attenuation even over distances of a just few metres because of the impurities that they contained. (Just think of the transmission of light when looking at a sheet of glass viewed sideways).

Enter two CSIRO scientists from the Division of Tribophysics (later Materials Science), then situated in the grounds of the University of Melbourne. Graeme Ogilvie (1924 – 2001) and his younger colleague Rod Esdaile (1939 – 2008) had the brilliant insight that clear liquids would be much easier to purify than solids such as glass or silica. Thus for example organic solvents such as the then common dry-cleaning fluid tetrachloroethylene, could have impurities removed by repeated distillation and, if used inside hollow fibres, could lead to much greater transparency and hence much less light attenuation than the then best silica or glass. The idea was patented by CSIRO in 1971 and they set about producing capillary fibres, using the same hot pulling process that produces solid fibres. (It seems like a miracle of rheology that a hollow tube preserves its cross-sectional shape even while its diameter is reduced from centimetres to micrometres).

The filling of the capillary tubes is much more onerous than the purification of the filling liquid but was, nevertheless, achievable over kilometres of capillary fibres, and the resulting "light pipes" were capable of carrying light with attenuation of less than 10 decibels per kilometer, i.e. a factor of less than 100 in power - a world record at that time. That was quite a useful property for practical purposes and it led to a race between the Australians and an American consortium from the famous Bell Labs and the equally famous Corning Glass Company.

Figure 1. Graeme Ogilvie and Rod Esdaile with a drum of hollow fibre carrying a TV signal in 1972. Photo credit: CSIRO Archives.

Needless to say, the race was won by the American giants whose breakthrough was based on another insight, namely that gases were even easier to purify than liquids. Starting with hyper-pure, semiconductor-grade silicon, they reacted it with hyper-pure hydrogen to produce hyper-pure Silane – SiH_4 - the analog of Methane - CH_4. Burning Methane in an atmosphere of pure Oxygen produces water vapour plus CO_2. In an analogous process, burning Silane in pure Oxygen also produces water vapour, plus SiO_2 - that is pure silica - a solid, in the form of a white soot.

If carried out inside a hollow silica tube, the burning of Silane thus leads to the deposition of the "white soot" on the inside wall of the tube. Heating to melt the soot, and then collapsing the hollow tube until the central hole disappears, gives rise to a solid pre-form which, when heated and drawn gives rise to a solid fibre, with a very pure central core.

The resulting optical fibre had some teething troubles, to do with inclusions of tiny bubbles of H_2O right on the axis (the worst possible region), due to incomplete collapse of the hollow tube. However, eventually the record for minimum attenuation was reduced to around 7 decibels per kilometer – a factor of 5 in power. This was clearly much superior to the Australian liquid-filled model – which never got better than about 10 dB/km. The development of the liquid-filled capillary fibre was then abandoned by the CSIRO.

But that was by no means the end of the story - a Japanese company did even better than the Americans. Using the same chemical process, they too proceeded to burn the Silane in an atmosphere of Oxygen - but not inside a hollow tube but just below a solid rod of Silica so that the same hyper-pure "white soot" was deposited on the bottom of the vertically held solid rod. The rod was then slowly

raised, keeping a constant distance above the flame, to yield a long cylindrical "pre-form".

After many further refinements, in the form of refractive index control by doping, single mode-optical fibres and so on, this process became the industry standard. Forming a partnership with the Australian company Olex, the Japanese company Sumitomo together with the Italian company Pirelli Cables built a factory just outside Melbourne. The joint company called "Optix Australia" ended up producing all the optical fibre cables linking all of Australia and creating a very valuable export product.

That is the end of the optical story, but the story of hollow fibres lives on. Abandoned by the CSIRO, the valuable expertise gained in their production led to the establishment of another, wholly Australian industry, in the form of a company called Scientific Glass and Engineering which still manufactures and exports capillary tubes, manufactured by similar fibre-pulling machines, for use in glass capillary columns for gas chromatographs that are used in analytical chemistry and medical applications.

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

Events

22-27 November 2015 IONS-KOALA 2015

KOALA (Conference on Optics, Atoms and Laser Applications) is Australia's only student conference in the fields of optics, quantum optics, atom optics, photonics and laser technology and will be held at the University of Auckland from Sunday 22 to Friday 27 November 2015. ionskoala2015.osahost.org

29 November - 3 December 2015 ANZCOP 2015

The Australia and New Zealand Conference on Optics and Photonics 2015 will be held at the University of Adelaide from 29 November to 3 December 2015. It integrates the Australian Conference on Optics, Lasers and Spectroscopy (ACOLS) and the Australian Conference on Optical Fibre Technology (ACOFT), and ANZCOP 2015 is the second such conference, following the successful ANZCOP 2013 held in Perth. ANZCOP 2015 will include a wide variety of plenary talks, including the Advanced LIGO project and the latest developments in bio-photonics, and a plenary by the 2015 Frew Fellow: Professor Ursula Keller of ETH Zurich. anzcop2015.com.au

6-9 December 2015 SPIE Micro+Nano Materials, Devices, and Applications

The SPIE international symposium on Micro+Nano Materials, Devices, and Applications will be held at the University of Sydney from 6 to 9 December 2015. This biennial conference will be a multidisciplinary forum with a focus on research that has enabled promising new materials and applications across many fields, including photonics, energy, security, information, and medicine. The symposium is an interdisciplinary forum for collaboration and learning among top researchers in all fields related to nano- and microscale materials and technologies. This event will focus on nanostructured and biocompatible materials, medical and biological micro/nanodevices, micro/nanofluidics and optofluidics, nanophotonics for biology and medical applications, plasmonics, solar cell technologies, and fabrication. spie.org/AU/conferencedetails/micro-plus-nano

7-11 February 2016 ICONN 2016

The International Conference on Nanoscience and Nanotechnology 2016 will be held at the National Convention Centre, Canberra from 7 to 11 February 2016. The aim of ICONN 2016 is to bring together Australian and International communities (students, scientists, engineers and stake holders from academia, government laboratories, industry and other organisations) working in the field of nanoscale science and technology to discuss new and exciting advances in the field. ICONN will cover nanostructure growth, synthesis, fabrication, characterization, device design, theory, modeling, testing, applications, commercialisation, and health and safety aspects of nanotechnology. ausnano.net/iconn2016

ICONN 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. osa.org/en-us/meetings/optics_and_photonics_congresses/photonics_and_fiber_technology

4-8 December 2016 AIP Congress and Asia Pacific Physics Conference

The 13th Asia-Pacific Physics Conference in conjunction with the 22nd Australian Institute of Physics Congress will be held in the Brisbane Convention Centre from Sunday 4 to Thursday 8 December 2016. This joint meeting will enhance links in the Asia-Pacific region and will incorporate the AOS Annual Meeting.

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osa.org/energyopc

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The Light, Energy and Environment Congress is comprised of four meetings, and is the continuation of the congress held in 2014 in Canberra.

See each meeting for details regarding topic categories, submission requirements and invited speakers.

- Optical Nanostructures and Advanced Materials for Photovoltaics (PV) osa.org/pv
- Optics for Solar Energy (SOLAR) osa.org/solar
- Optics and Photonics for Energy & the Environment (E2) osa.org/e2
- Solid-State and Organic Lighting (SOLED) osa.org/soled

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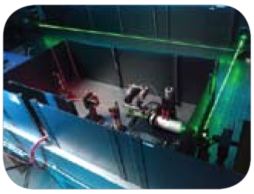

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Product News

Q-Smart 450: The Most Flexible and Simple Nd:YAG Lasers from Quantel

The Q-smart series of Nd:YAG lasers from Quantel offer users a simple, yet powerful system that ensures no-fuss operation and optimal performance at all times. Monolithic construction and a compact design provides superior beam geometry and the Q-touch screen interface makes the laser even easier to operate, with the following benefits:

- NEW: highest energy at 532 and 355 nm with a single doubling crystal
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- 2 year warranty on optics and mechanics

For users requiring higher energy, Quantel also offers the Q-Smart 850 with 850mJ at 1064nm.

New! Double-pulse Laser with 266nm Output for Combustion Studies

Quantel has recently announced the newest addition to their successful EverGreen product line; the EverGreen 266.

Particle Image Velocimetry (PIV) is typically performed with 532 nm lasers, however researchers are increasingly looking at different, more subtle effects that are best imaged via UV excitation. The EverGreen 266 allows users to image in the UV, thus permitting precise measurements of velocity and density fields for certain combustion experiments that are difficult to measure with traditional techniques.

The EverGreen 266 offers the following key features:

- 2 x30 mJ pulses at 266nm
- Double pulse operation up to 15 Hz
- Simple, hands-free switching between 532 nm and 266 nm
- Compact, rugged and easily moved between experiments

EverGreen HP: With Energy up to 2 x 340 mJ at 532 nm

The EverGreen product line is further expanded with the new high power EverGreen HP platform. The EverGreen HP is available in several versions with a variety of energy and repetition rate combinations such as:

- 2 x 340mJ at 15Hz
- 2 x 100mJ at 100Hz
- 2 x 50mJ at 200Hz

EverGreen HP offers the same ease of use, ruggedness and compact design as the other members of the EverGreen family and is an ideal choice for PIV applications requiring high pulse energy or repetition rate.

For further information please contact Coherent Scientific at sales@coherent.com.au or 08 8150 5200

New Precision Linear Stage Series

Warsash Scientific is pleased to announce the release of the all new L-511 precision linear stage series from PI (Physik Instrumente). The stages achieve unidirectional repeatability up to 0.1 µm and minimum incremental motion of up to 0.02 µm.

The L-511 are equipped with stepper motors. Optional direct-measuring position encoders ensure a high resolution in a range of a few nanometers. Versions with DC motors with dynamic ActiveDrive control as well as with DC gear motors are in the pipeline.

Due to their ball screw, the stage series is suitable for applications in industry and research that require high cycle rates and velocities up to 50 mm/s. The linear stages are available for travel ranges of 52 mm, 102 mm and 155 mm.

Recirculating ball bearings that are mounted on precision-ground profiles ensure a high guiding accuracy of +/-50 µrad per 100 mm travel range and a load capacity up to 100 N.

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For single-axis control, PI offers the easy to operate digital C-863 and C-663 Mercury motion controllers for DC motors and stepper motors. For DC motor control of up to four axes, the C-884 is available.

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Warsash Scientific is pleased to announce the release of the all new HELIOS brand of modular uniform sources for absolute calibration of imagers and sensors from Labsphere, Inc., a global leader in photonics test and measurement equipment and services. Labsphere provides innovative solutions for a wide range of applications including LED/SSL lighting, remote sensing, imager/consumer camera, automotive, defence and security, health and biomedical optics to both Production and Research environments.

The HELIOS product line offers a solution to industry needs today where no "one-size-fits-all" testing solution will serve every customer. There are 54 standard configurations that span a huge range of validated, tested and characterized solutions. Additionally, the product's modular design, open architecture software, flexible spectrums and future-expandability enables users to meet demanding testing challenges in areas of hyperspectral, multispectral, SWIR and VIS-NIR optical regimes.

"Labsphere recognized that the market requires a standard system and we have spent several years developing this. We have created a family of products to serve the needs of diverse users with the advantages of standard product" said Imaging Products Marketing Director, Chris Durell. He continued "a configured standard will fit your specific need but have smooth installations, robust and tested designs, user friendly platform software, and you will be able to upgrade them as we add features and options to the platform, significantly extending the life of your tool."

Today, researchers are more likely to work in collaboration with colleagues than ever before. A stable platform of instruments, with in-depth calibration data and robust designs, allows for joint efforts between labs or at enterprise accounts doing research in multiple locations.

Imaging Products Marketing Director, Chris Durell conveyed, "Labsphere market leadership demands that we be responsive to the ever changing technology and ever tightening uncertainty specifications in a dynamic way that allows the product to grow and change with customers' test needs. Coupled with unparalleled characterization of the systems, and a 'Family' of system solutions that can serve needs from R&D to production to full, outdoor-in-field capability, we are bringing laboratory quality solutions to every aspect of image and sensor testing needs today."

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In addition to absorbance, reflectance, fluorescence and Raman spectroscopy of microscopic samples, the 20/30 PV™ from CRAIC Technologies and available exclusively in Australia from Warsash Scientific gives you the ability to study photoluminescence spectroscopy. Photoluminescence spectra gives even more information about samples and delivers a more complete pictures of electronic structures.

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Upon a molecule's absorption of a photon of a particular wavelength or energy, the molecule promotes an electron from the ground state to an excited state. The excited state in most molecules is labelled as a singlet state. These types of states can re-emit a photon quickly, producing fluorescence. In addition to emitting quickly, fluorescence also has a short lifetime. In other words, the emitted light lasts only a short time and only gives information about that particular singlet state.

However, singlet states are not the only accessible electronic states and excited molecules can undergo a phenomenon called intersystem crossing, where the excited electron is transferred to a state of higher multiplicity than a singlet; for example a triplet. Triplet states also emit photons (of different wavelengths than singlet states) and these emissions occur for much longer time periods, on the order of milliseconds to minutes and even hours (think glow in the dark!). This type of emission is often referred to as phosphorescence.

Photoluminescence encompasses fluorescence, phosphorescence, and any type of photon emission that a molecule or sample exhibits. The key here is that the emission does not have to be optically stimulated itself. This exciting and informative type of emission occurs in a wide range of molecule types: from engineered materials to biological to devices! And CRAIC Technologies' instruments provide numerous solutions to study the PL of samples on the micro scale, down to a single square micron, and of large-scale samples but with extremely high spatial resolution.

"As more products and devices utilize ever smaller photoluminescent (PL) light sources in ever more demanding environments, the ability to test those devices with ultra-high spatial resolution and fidelity becomes increasingly important" states Dr. Paul Martin, President of CRAIC Technologies. "CRAIC Technologies microspectrometers are ideally suited for both research and quality control of such devices. Microspectrometers can quickly characterize and qualify PL devices allowing for researchers and manufacturers to develop ever better light sources."

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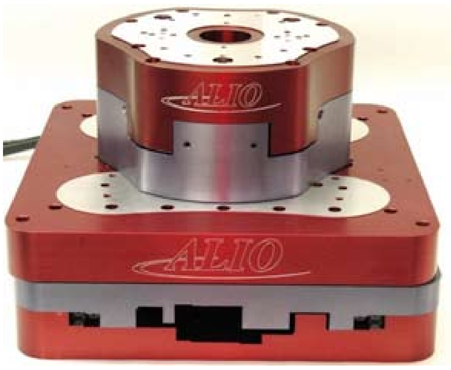

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Superchiral Light and the Flow of Zilch

by Tim Davis

Chirality is a property of biological systems with a profound impact on biological function. The chiral properties of large molecules are often discovered from their response to circularly polarised light but the interactions are generally very weak. However, recent research has shown that the strength of the chiral interactions can be enhanced significantly by creating optical fields that are more chiral than circularly polarised light. Such fields are superchiral.

The word "chiral" derives from the Greek word *kheir* meaning "hand" and refers to a geometric asymmetry whereby a structure and its mirror image are not superimposable. Our hands are chiral in the sense that the mirror image of our right hand is equivalent to our left hand. Both hands can only be superimposed palm to palm or back to back but cannot be superimposed with both palms facing us. This type of asymmetry is common in nature and leads to such chiral structures being described as left or right handed. The DNA double helix is a right-handed chiral structure with a form that we most often associate with chirality - that is a screw-like structure.

Chirality in biology

Chirality is important in biology because many of the molecules or proteins created by biological systems are themselves chiral (an example chiral molecule is shown in Fig. 1a). Moreover the response of a biological organism to a particular molecule often depends on how that molecule fits into a particular receptor site, and that in turn depends on shape. Very often a molecule can have two different shapes even though it has the same chemical composition. An example is glucose, a common sugar formed by plants. The molecule has two chemically identical forms but with different handedness - dextrose and levulose. In chemistry these molecules are described as enantiomers. Natural lifeforms do not produce levulose and, unlike dextrose, it cannot be used by biological organisms as a source of energy. Its left-handed chiral structure is incompatible with the enzymes used to convert sugars into energy-rich molecules, such as ATP, that are used throughout the cell. Understanding molecular chirality is important in developing new pharmaceuticals, since a molecule of a given chemical composition can be designed with a chirality so that it is readily absorbed in the body, or alternatively it can be designed to persist in the presence of destructive enzymes.

Chirality in molecules was first discovered by their influence on light. The direction of rotation of the polarisation of light passing through, for example, a solution of sugar depends on which enantiomer of sugar is being used - dextrose will rotate the plane of polarisation to the right (dexter meaning "on the right") whereas levulose will rotate the polarisation to the left. The variation with wavelength of this *optical rotary power* is known as *optical rotary dispersion* and yields information on the geometry of molecules. Another optical property is *circular dichroism*, which refers to the difference in the absorption of left circularly polarised and right circularly polarised light. These chirally sensitive (chiroptical) spectroscopic techniques are used extensively in biology as incisive probes of the three-dimensional aspects of biomacromolecular structure [2]. The problem is that chiral effects are very weak and experiments are very difficult to perform when only small quantities of materials are available. So how can chiroptical effects be enhanced? To answer this requires an understanding of chirality in light.

Circularly polarised light has electric and magnetic field vectors rotating about the direction of propagation. The fields are perpendicular to one another and in air are shifted 90 degrees out of phase. This is quite different from linearly polarised light in which the electric and magnetic field vectors oscillate in phase. The direction of rotation can be clockwise or anti-clockwise, that is left or right handed (Fig. 2), and the reflection asymmetry means that circularly polarised light is chiral. It is not surprising therefore that circularly polarised light is important for probing the chiral properties of molecules.

Zilch

What is more interesting is that a measure of the chirality of light can be defined. This arose out of a study of the conserved quantities that can be constructed out of Maxwell's equations. Apart from the usual conservation of energy law for a time-periodic electromagnetic field, Lipkin [3] found an additional 9 conservation laws yielding a complete set of 10 conserved quantities. Despite this "mathematical *embarras de richesses*" most of these quantities lacked any ready physical interpretation, and so Lipkin named them "*zilch*". In his analysis, Lipkin noted that three of the zilches were not transported by linearly polarised waves but had non-vanishing flows accompanying circularly polarised waves. Moreover he found that the direction of the flow reversed with the screw sense of the wave. To quote Lipkin: "Unlike energy and momentum, which are always transported in the direction of propagation of the wave field, zilch can evidently be transported either in this direction or in the opposite (or retrograde) direction, depending upon the sense of circular polarisation of the wave. This behavior of zilch flow is somewhat similar to what would be expected for quantities representing an intrinsic spin of the field, and is suggestive of a possible direction for the physical interpretation of zilch. Certainly, the occurrence of this similarity in what is strictly a classical field theory would appear to merit further investigation." In fact, as pointed out by Tang and Cohen [4], Lipkin's zilch provides a good measure of the chirality of the light field. More importantly it points to how to construct a light field that is more chiral than circularly polarised light.

Lipkin's chiral zilch can be expressed mathematically by writing the electric field vector of an electromagnetic wave as a complex number **E** and that of the magnetic induction as **B**. Then the non-vanishing component of zilch takes the form $C=-(\omega\varepsilon_0/2)\mathrm{Im}(\mathbf{E}^*.\mathbf{B})$ where ω is

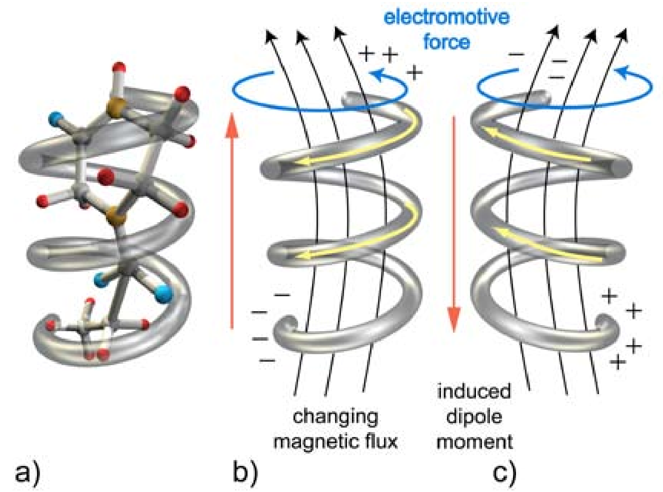


Figure 1. a) an example of a chiral molecule - oxopiperazine [1]; b-c) the chiral molecule can be modelled by a helix with a dipole moment induced by an applied magnetic field that depends on the handedness. A changing magnetic flux creates an electromotive force that drives electric charges along the helix in the same direction. If the helix is right handed (b) the electrons are driven down, but for left handed (c) they are driven up.

the frequency and ε_0 is the permittivity of free space. (Here it is assumed that the fields oscillate in time as exp(-iωt)). This expression provides a measure C of the chirality of the wave. It involves the imaginary component of the projection of the complex conjugate of the electric field vector onto the magnetic induction vector. What does this mean? If we write $\mathbf{E}=\mathbf{E}_0\exp(i\phi_E)$ and $\mathbf{B}=\mathbf{B}_0\exp(i\phi_B)$ then $\mathrm{Im}(\mathbf{E}^*.\mathbf{B})=|\mathbf{E}_0 . \mathbf{B}_0| \sin(\phi_B-\phi_E)$. Non-zero chirality is obtained when the electric and magnetic fields have vector components that are parallel and, simultaneously, are oscillating with a phase difference. This is precisely the condition that occurs with circularly polarised light. Moreover, circularly polarised light has the electric and magnetic fields shifted in phase by 90 degrees, and this phase shift aligns the two vector fields at different moments in time, which maximises the chirality measure. In this sense circularly polarised light has the largest possible chirality. Linearly polarised light has the electric and magnetic fields perpendicular and oscillating in phase, and therefore has no possible chance of being chiral.

It is interesting to note that the chirality measure C as derived from zilch determines the strength of the circular dichroism associated with a chiral molecule. It comes about in the following way. A chiral molecule can be thought of as having a helical structure [5]. While most chiral molecules don't look like helices, in three dimensions they are associated with a "twist" that can be modelled as a section of a helix (Fig. 1a). The electrons in the molecule will move slightly under the action of an electromagnetic field, thereby electrically polarising the molecule. In this sense the molecular helix looks a little like a coil threaded by the oscillating magnetic flux of the incident light field (Fig. 1b). The changing magnetic flux induces an electromotive force that tries to drive the electrons towards one end of the helix, and positive charges to the opposite end, creating an electric dipole moment in the molecule. Although the direction of the electromotive force is independent of the chirality, the end of the coil to which the electrons are driven depends on handedness. A right-handed molecule will polarise in one direction (Fig. 1b) and a left-handed molecule will polarise in the opposite direction (Fig. 1c). Using Condon's model [5], the induced dipole moment is proportional to the time derivative of the magnetic field, or $\mathbf{p}=i\beta\omega\mathbf{B}$ where β is a complex proportionality constant, similar to the electric polarisability. From classical electromagnetic theory, the rate at which work is done on an oscillating current **J** is given by the real part of $\mathbf{J}^*.\mathbf{E}$. For the oscillating dipole **J** is proportional to $-i\omega\mathbf{p}$ and so the work done is $-\beta^*\omega^2\mathbf{B}^*.\mathbf{E}$. Since the imaginary part of β (which we write as β") is responsible for the circular dichroism, then the absorption of light by the chiral molecule is given by
$\beta''\omega^2\mathrm{Im}(\mathbf{B}^*.\mathbf{E})=-\beta''\omega^2\mathrm{Im}(\mathbf{E}^*.\mathbf{B})$ which is the zilch that measures optical chirality. That is, maximising the chirality of an optical field will maximise the circular dichroism associated with a chiral molecule.

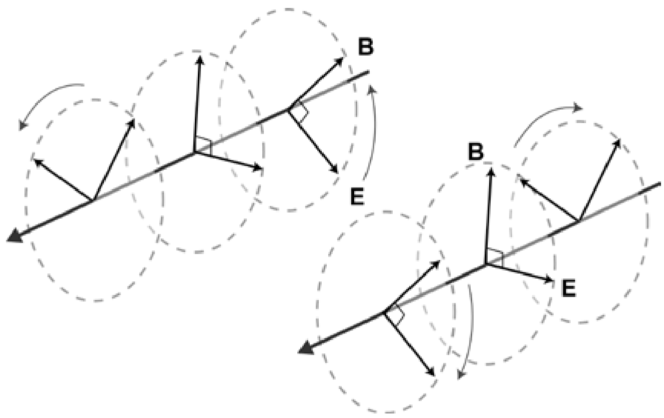
Superchiral fields and localised surface plasmon resonances

Since the chirality measure C controls the strength of the interaction with chiral molecules then to enhance the circular dichroism the chirality of the incident light must be increased. This would give it a chirality greater than that of circularly polarised light. Light fields with such an unusual property have been termed *superchiral* fields. The first demonstration of superchiral interactions was by Tang and Cohen [4, 6] who investigated ways of enhancing the *dissymmetry* factor, a measure of the fractional difference in the rates of excitation between left- and right-circularly polarised light. They showed that a standing wave of two counter-propagating circularly polarised light beams could enhance the dissymmetry factor by an order of magnitude over that of circularly polarised light alone.

From the definition of C it is clear that the key to enhancing the chirality of the optical field over that of circularly polarised light is to 1) increase the electric field **E**; 2) increase the magnetic induction **B**; 3) ensure the fields oscillate 90 degrees out of phase; 4) ensure the fields are parallel to one another. Remarkably, localised surface plasmon resonances naturally satisfy three out of these four requirements, and by simple choices of geometry the fourth requirement can be obtained, resulting in large enhancements of chirality and chiral interactions with molecules.

A localised surface plasmon is an electric charge wave that can be excited over the surface of a metal nanoparticle by light. The charge wave propagates around the surface resulting in interference. At certain optical frequencies the interference is constructive resulting in a localised surface plasmon resonance. Because this is a resonance phenomenon, optical energy accumulates in the plasmon wave creating large oscillating electric charge at the metal particle boundaries. A well-known property of a resonance is that the

Figure 2. A sketch showing the rotation of the electric **E** and magnetic **B** field vectors for circularly polarised light. The direction of the rotation (screw-sense) determines the handedness or chirality of the light.



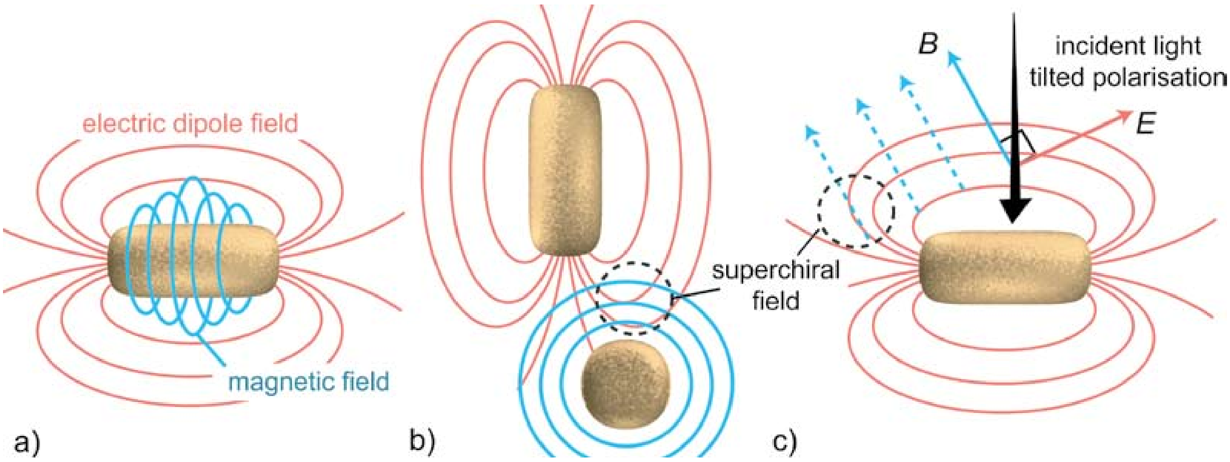


Figure 3. The creation of superchiral fields using localised surface plasmon resonances in a metal nano rod. a) The fundamental surface plasmon mode produces a dipole electric field perpendicular to the magnetic field, which oscillate 90 degrees out of phase. b) A superchiral field can be created using two metal nano rods arranged so that the electric field from one rod is parallel to the magnetic field from the other; c) A single nano rod interacting with linearly polarised incident light can generate a superchiral field in regions when the surface plasmon electric field is parallel to the incident light magnetic field.

oscillations are 90 degrees out of phase with the driving force, and this also applies to the localised surface plasmon. The strong electric fields generated by the charges oscillate 90 degrees out of phase with the incident light field. Moreover, the current flow associated with this charge oscillates in phase with the incident electric field. The magnetic field created by the current flow is then also in phase with the incident electric field and 90 degrees out of phase with the plasmon electric field. Thus the plasmon is associated with strong electric and magnetic fields oscillating 90 degrees out of phase, exactly the condition for chiral fields. The only catch is that the magnetic field is always perpendicular to the electric field (Fig. 3a). The simple solution is to use two metal nanoparticles, arranged so that the electric and magnetic fields are parallel in some region of space (Fig. 3b). Calculations suggest that superchiral fields orders of magnitude stronger than that of circularly polarised light can be created with these structures [7-8]. Following the work of Tang and Cohen [4, 6], Hendry and colleagues [9] demonstrated huge enhancements in the dissymmetry factor associated with proteins in the presence of chiral metal nanostructures. This large enhancement was attributed to the presence of localised surface plasmon resonances in the chiral metal structures that responded differently to the handedness of the incident light.

Something from nothing

Surprisingly, it is possible to create chiral optical fields using *linearly* polarised light and a *non-chiral* metal nanostructure. Since the plasmon electric field is 90 degrees out of phase with the incident electric field, it will also be 90 degrees out of phase with the incident magnetic field. By directing the incident light field at some angle to the metal particle, it is possible to excite a surface plasmon with a part of its electric field aligned the magnetic field of the incident light (Fig. 3c). This configuration, likewise, is predicted to create regions of high chirality, or superchiral light fields [8]. But it is important to remember that zilch is a conserved quantity. The incident field and the surface plasmon have no intrinsic chirality beforehand and therefore the total chirality must be zero. Instead the electromagnetic field develops regions of both positive and negative chirality, such that the total remains zero. In this respect the superchiral regions remain close to the metal particle and are not found in the far field. The positive and negative zilch propagating into the far field cancel out.

The use of localised surface plasmons for creating superchiral fields is an example of engineering the optical near fields. This concept, that we can control and manipulate light at the nanoscale to modify light-matter interactions, is a powerful one, and there are many more opportunities to explore. In this article it was shown that by near-field engineering, light fields can be generated with properties that were never-before thought possible. In particular, optical near-fields with strong chirality can be created from light fields and structures that have no chiral property whatsoever. Which just goes to show, although you can't get something from nothing, you can get plenty from zilch.

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INSPIRED WORK

Smartphone Spectroscopy: The Beginnings of the IoT-Compatible, Ubiquitous Lab-in-a-Phone Network

by John Canning

Smartphone instrumentation is revolutionising biomedicine, environmental monitoring and much, much more. From the use of the various diodes, AMOLED screens for sensing to full on dual spectrometers, here we briefly review bringing smartphone spectroscopy to life.

When a person holds their smartphone in their hands they are holding arguably one of the most advanced technologies the world has ever seen. According to an infographics compiled by Experts Exchange [1] a Smartphone Samsung Galaxy 6, for example, is currently credited with the power of 18 Cray-2 supercomputers from 1985. But this technology is more than just improving computer chips - it is driven by a commercial market unmatched in size because of consumer desire, and willingness to pay for communication with entertainment, cognizant or otherwise. This commercial opportunity is driving technological progress to shrink components at a rate that exists nowhere else, mass produce CMOS imaging chips as good as CCDs if not better, use the smallest gyros for accurate positioning, create and integrate the most energy efficient compact red, green and blue (RGB) light emitting diodes (LEDs) for displays and create equally efficient white LEDs for illumination. All these technologies run for hours on a single and relatively tiny battery package and are controlled by a host of devices and signal processing software that in principle anyone can modify, create and upload via the internet (at least in the Android market to date). In fact, it is likely that the equipment in the pocket of nearly everybody has superior componentry and control than much of the instrumentation technology in the best laboratories.

To illustrate this power, let us consider its ability to revolutionise spectroscopy and a standard spectrometer (Figure 1). It is not going to have detectors with the resolution of a smartphone, relying instead on often inferior technology but with optical path lengths scaled up until a particular resolution is achieved - double monochromators may even use multiple traverses to increase resolution. However, there has also been substantial progress in the mini-bulk spectrometer field. Many companies nowadays sell compact and optimised spectrometers, using better CMOS arrays, some of which have benefited from smartphone development, and better dispersive elements and folded paths to offer new portable instrumentation (often with no moving parts). These are sold both as fully functioning instruments that need to be accompanied by separate optics or as advanced optoelectronic modules to be integrated into customer specific industrial sensing systems. Unfortunately, the niche markets involved in the sensor world as they stand limit the justification for technological development of the kind seen within smartphones, which in turn limits the costs that can be afforded.

Why can't we leverage off the

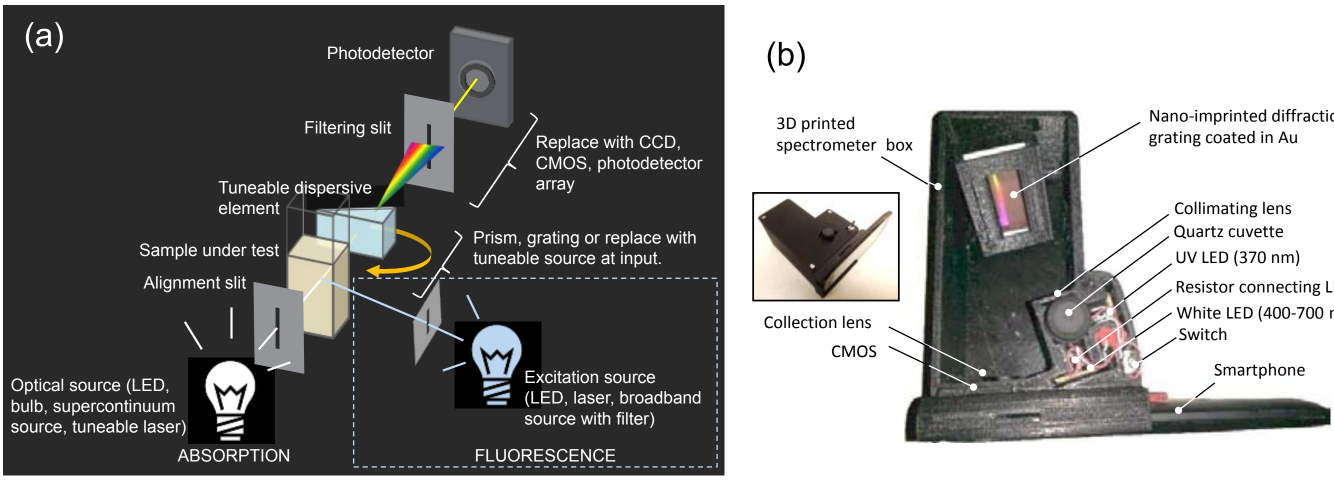

Figure 1. (a) The principle behind simple absorption and fluorescence spectrometers. Both involve an optical or excitation source, tuneable dispersive element and photodetector. Other more robust variations may replace the photodetector with a CCD or CMOS array and fix the dispersive element whilst still others may, instead, use tuneable sources. In the fluorescence case this excitation source is often 90° making it relatively simple to combine the two; (b) the smartphone dual absorption and fluorescence spectrometer [3]. Shown are all the components which make up its structure. The optical source can be the smartphone camera white LED or an external source can be inserted into the smartphone circuitry. Here a 370 nm UV LED is shown; in principle any spectral emitter can be integrated provided it can run off the smartphone battery. The circuit was modified slightly so that both white LED and external diode can be run without any problems. For anything outside of the spectral window of the silicon based CMOS chip, an additional detector or array operating in that window can be similarly inserted. Inset shows the system with cover on.

smartphone platform and use all of its advanced technology to build a range of portable instrumentation such as smartphone spectrometers? Why not exploit the power of a smartphone driven purely for imaging purposes and a crazy desire for ultra-high resolution selfies? Certainly the signal processing required for taking spectra and processing data is already there and in combination with wireless and Bluetooth capability the potential for superior portability, when powered by the smartphone battery, offers a tremendous advantage over these new generations of compact spectrometers. Indeed, accessibility becomes as important as portability - imagine in the middle of Africa where no power exists but everyone has a smartphone charged by the local village shop, perhaps with a solar charger, that requires spectral analysis of biological pathogens or chemicals. A simple but less accurate integration of a recent colorimetric based paper test for Ebola [2] can quickly illustrate the global game-changing role smartphones can play. And ideally in real-time so that measurements in one place can be correlated with those in another - all the while the ability to use the same instrumentation to communicate to one's colleagues or family is retained. In this way, one can speculate that something as tragic as the recent Ebola crisis could be better managed and contained if the long awaited IoT was in place and data collected from a smartgrid of smartphones, shared and mapped live through that grid - a case of novel spectroscopy mapping of an unheralded kind. This seems like a desirable future - can we do it?

Typically, a spectrum is a continuous distribution of radiant energy with varying intensity and frequency dispersion. Most commonly we are familiar with it being obtained using a broadband source such as a white light emitting diode or spectrally sweeping a narrow band source such as a tuneable laser through a dispersive component or material. The sources can vary tremendously and occupy any part of the electromagnetic spectrum. The interaction between the radiative energy from the source and the sample being probed is classically described in terms of absorption, emission and scattering. Figure 1 (a) summarises the basic layout of an ideal, simple spectrometer for absorption - given that much absorption work occurs in the visible we can consider the source to be something like a white light emitting diode (LED). Our smartphone has one of these - it is used to illuminate areas so they can be imaged through the camera lens onto the high resolution CMOS chip. Thus we recognise immediately we have the basic hardware components of the absorption spectrometer in our smartphone - an optical source and a detector. In this case the detector is an array of accurately known receivers. What is needed and which is not present is the dispersive element splitting the white light into its constituent parts after passing through a sample. Figure 1 (a) depicts a dispersive prism but to use this we would need to have a folded path to reflect the spectra onto the CMOS chip, with red light at one end and blue at the other. A much simpler approach is to use a dispersive, reflective grating. Figure 1 (b) shows a simple low cost grating fabricated by polymerisation of a polymer gel over a mask template before sputtering a layer of gold. The template structure "nano-imprints" a periodic structure which is translated into the gold film. This gold grating can then be used to disperse a collimated beam from the white LED of the smartphone passed through a sample onto the CMOS chip. A software app can then take the signals from the chip and plot the corresponding spectra (after the instrument is calibrated). There are other ways and other elements one can do this with but this example works well enough and allows us to modify the grating at will.

Multiple instrumentation or functionality on a smartphone [3] is more desirable still and we build on earlier work demonstrating how a smartphone screen RGB display itself can be used to excite fluorescent dye-doped, large spheres self-assembled from nanoparticles [4] - the beginning of "lab-in-a-phone", particularly attractive for biosensing and biomedical applications. A dual absorption and fluorescence spectrometer is shown in Figure 1 (b). The excitation source is often placed at 90^0 to reduce the likelihood of excitation light reaching the photo detectors. Further, the optical excitation power density required is often much higher than that for absorption

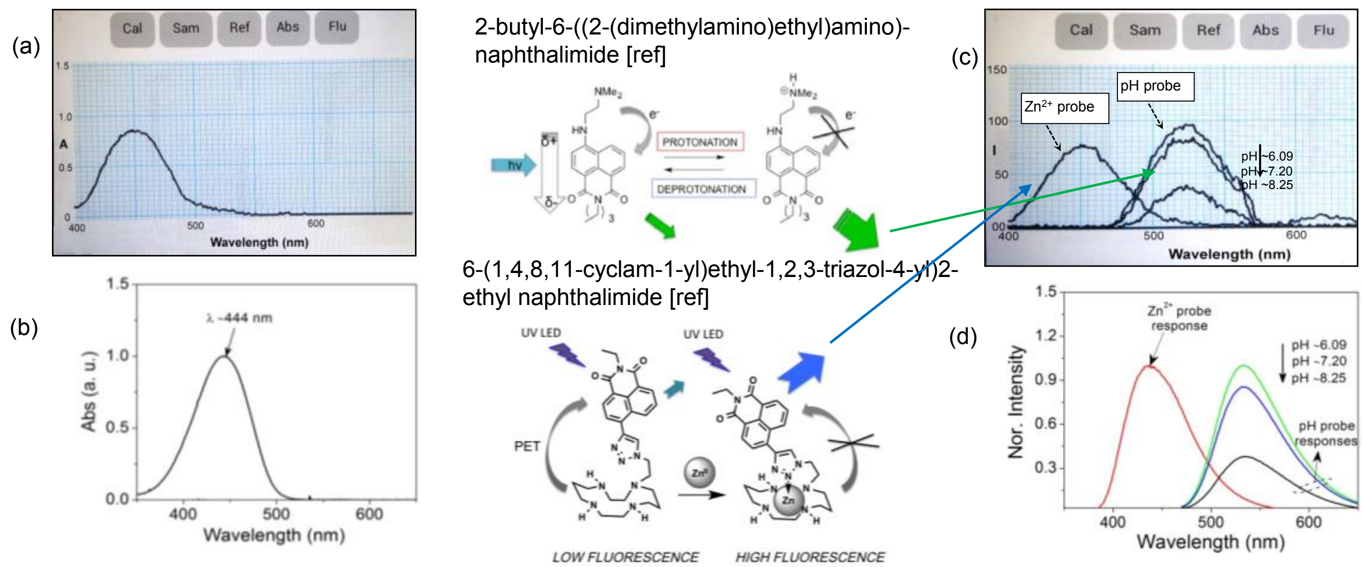

Figure 2. Spectra measured on the smartphone and benchtop spectrometers [3]. Absorption spectra of the pH probe acquired with: (a) the smartphone, and (b) the benchtop spectrophotometer (Shimadzu UV-2401PC). Fluorescence spectra of pH and Zn^{2+} probe acquired with: (c) the smartphone and (d) the benchtop fluorimeter (Varian Cary Eclipse). The fluorescent markers are tailored napthalimide based dyes, although other species can be used. The optical resolution over a 300 to 700 nm span is 0.42 nm/pixel group which can be reduced to < 0.2 nm when noting that the pixel group in this smartphone is made up of three distinct RGB pixels lined up in the direction of interrogation.

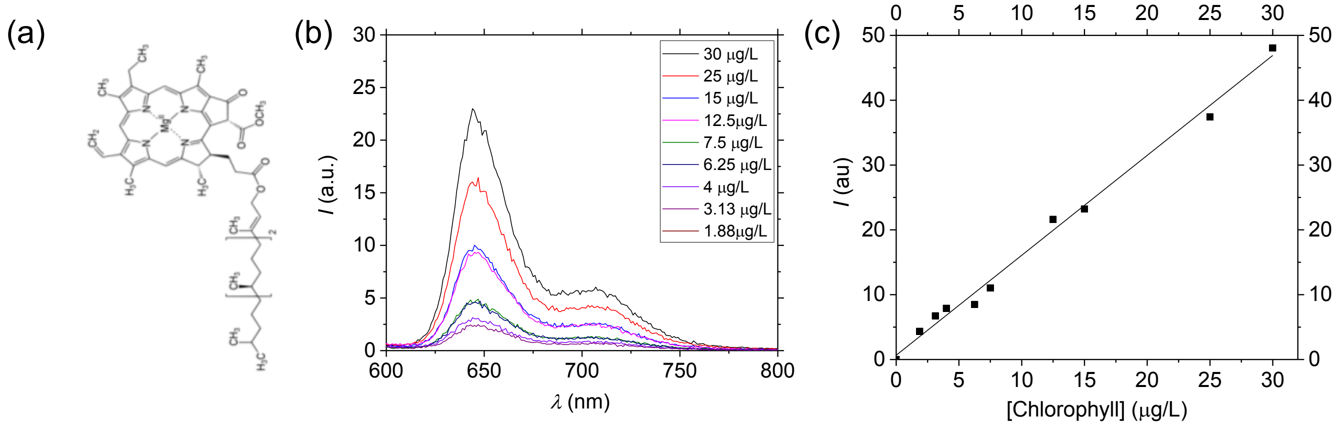

Figure 3. Smartphone spectrometer measurements of (a) chlorophyll: (b) spectra at different concentrations; (c) direct power measurements with no dispersive element present. Modified from [13].

spectra and the quantum efficiency of the white diode may be quite small meaning significantly less light is generated than energy is put in. With current technology the illumination from the white LED, and indeed the individual RGB diodes making up the screen, are too low for most fluorescence applications without significant optics to collect stray light. At this point in time, it is sometimes necessary to integrate an additional source, bearing in mind that ideally we want to retain portability and global accessibility. The most immediate approach to address this is to use the smartphone battery for power - others have used smartphones for fluorescence spectrometer applications [5,6] but these have invariably required external power sources. Fortunately, low powered but efficient LEDs across the spectrum are available and increasingly even down to the deep UV and at other wavelengths outside the existing white and RGB bands - for specific fluorescence applications this becomes enabling.

The final configuration will look something like that shown in Figure 1 (b), a prototype we have built using 3D printing to fabricate the customised casing which includes both sample and mask supports. Other variations are feasible, such as those involving double concave mirrors to maximise signal collection and optimise collimation. Despite its compact size, we obtained a spectral resolution better than 0.2 nm, reflecting the high density of CMOS pixels. In this case a switch is used to alternate between absorption and fluorescence measurements though there is no reason with additional electronics why that cannot be automated. Here, the added blue or UV LED is placed at 90^0 whilst the white diode is used to pass through the sample, which is placed in a cuvette that can be inserted into the instrument. The Au-coated polymer mask is positioned such that it delivers light towards the CMOS chip and a small lens attempts to collimate light before reaching the prism whilst filters at the receiving end can be used to filter out any part of the spectrum so desired. In this particular model, the sample is standardised to a cuvette; however, there is scope for much broader variations including chambers for slides. We have also made spectrometers with optical fibres as the optical collection conduit [7].

Figure 2 illustrates samples measured using the smartphone spectrometer reported in [3] with absorption and fluorescence of two chemosensor dyes synthesized for pH and Zn^{2+} measurements respectively [8]. Monitoring changes in pH is one standard used to gauge water quality by many national water agencies [9] whilst fluctuations in Zn^{2+} within tissues are associated with a range of biomedical conditions, including wound healing, heart related problems such as ischemia, stroke and Alzheimer's disease. Using fluorescence to detect Zn^{2+} is consequently an area under considerable investigation [10].

In order to improve signal-to-noise, sensitivity and time response, monitoring in real applications is often undertaken as direct, fixed wavelength power measurements. In these cases, the actual spectra is not necessary given the integrated area, or power, can be used effectively for high resolution measurements for a given beam width, where the dispersive element is removed and the CMOS chip acts a straight photo detector [11]. Good correspondence for pH measurements against the data periodically published by the NSW state monitoring agency was obtained. Further, smartphone sensing can be used to map pH measurements in real time through the internet [12]. This leads to the concept of "IoT forensics", an approach alluded to earlier as of significant value for mapping real time spread, for example, of disease such as those that give rise to fear of a potential epidemic (it is not limited to smartphone sensors).

Direct power measurements provide better sensitivity. As part of the Talented Students Program, a group of 1st year undergraduate students under the mentorship of a 3rd year undergraduate were able to measure with the spectrometer the spectra of chlorophyll [13], Figure 3. Chlorophyll monitoring by direct absorption power measurements is another standard parameter often used in gauging water health [14]. Levels above 4 μg/L are considered problematic, indicating excessive leaching of farmland fertilizer into waterways. They found the sensitivity by measuring spectra where a considerable amount of light is lost in sufficient amounts to detect the levels considered unhealthy for water systems. Instead, Figure 3 (c) shows the results obtained by the students using a direct measurement of power to reduce the light intensity lost by the dispersive element per pixel. The students were able to achieve a noise floor < 1.8 μg/L with the existing spectrometer.

In conclusion, spectroscopy on a phone (or watch or tablet [15]) can be integrated into a network of thousands of other instruments monitoring, sharing and processing data to build real-time regional and global maps of a range of phenomena across medical, agricultural, environmental and other disciplines. Future variations may also include smartwatch spectrometers and the like. Ubiquitous "household" spectroscopy is enabled by extraordinary decreases in cost - basic smartphones are presently as

low as $US 25 [16]. Alternative power sources can also be used, as many others have, whilst recognising the specific needs and tolerances of a desired application. Whilst the benefits are clearly enormous, including a terrific example for the modern student to play with, a final note of caution is the potential danger this new IoT sensor "skin" of an increasingly intelligent network may bring - it may bring forth the "singularity" and therefore the end of human kind [17].

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