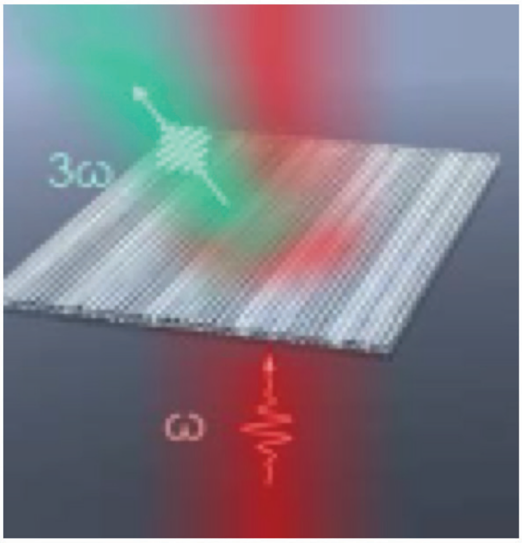
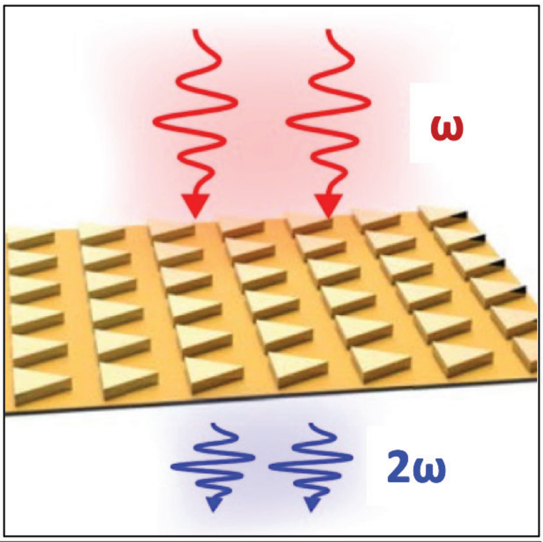
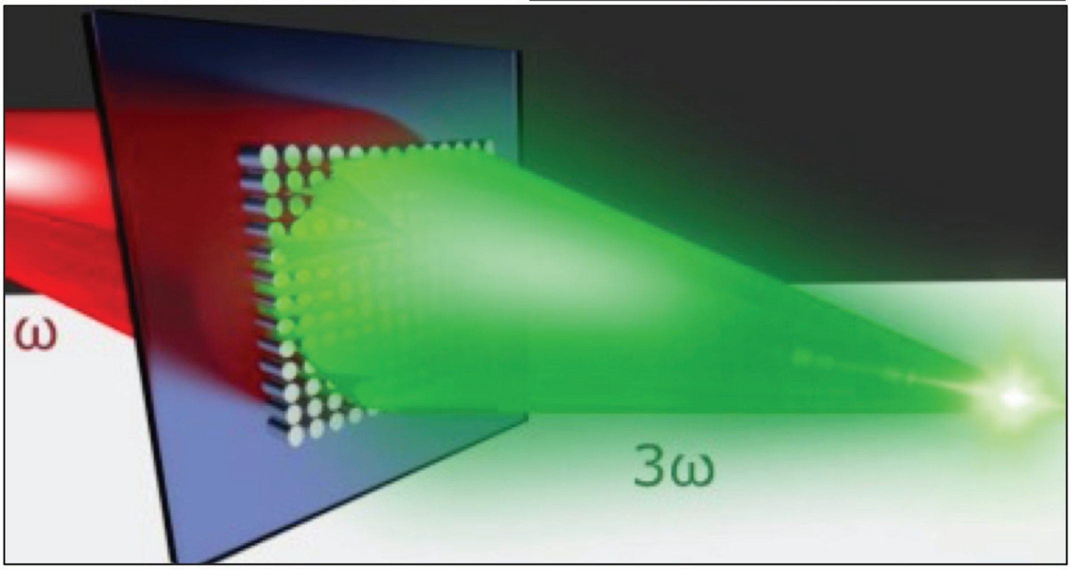
ANZOS News

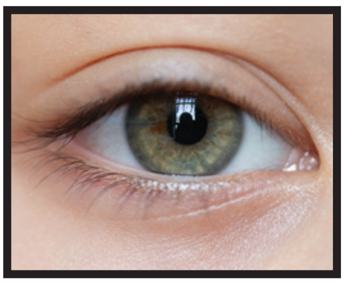
Volume 34 Issue 1
April/May 2020
ISSN 1832-4436

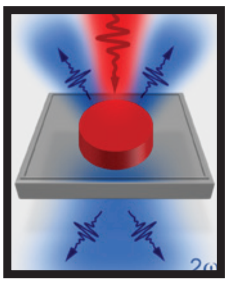






THE AUSTRALIAN AND NEW ZEALAND OPTICAL SOCIETY





THE AUSTRALIAN AND NEW ZEALAND OPTICAL SOCIETY ABN 63 009 548 387

ANZOS News is the official news magazine of the Australian and New Zealand Optical Society. Formed in 1983 as the Australian Optical Society (AOS), the Society is a non-profit organisation for the advancement of optics in Australia and New Zealand. Membership is open to all persons contributing to, or interested in, optics in the widest sense. In January 2020 the Council of the Australian Optical Society (AOS) changed the "trading name" of the Society to the Australian and New Zealand Optical Society (ANZOS) and adopted a new logo. See the ANZOS website for details on joining the Society.

Submission guidelines

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

Call for submissions!

Please consider writing something for the next issue.
We are looking for:

Scientific articles on any aspect of optics

Review articles on work in your lab

Conference reports from meetings you attend

Articles for the Optics in Everday Life section

General interest articles

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
- General Interest Article: Any item of interest to members such as reports on community engagement, science in society, etc.
- Article for Optics in Everyday Life section: An explanation of the optics behind any interesting effect, phenomenon, or device.
- News Item
- Obituary
- Book Review
- Cartoon or drawing
- Crossword or puzzle

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.

PHOTON SCIENTIFIC

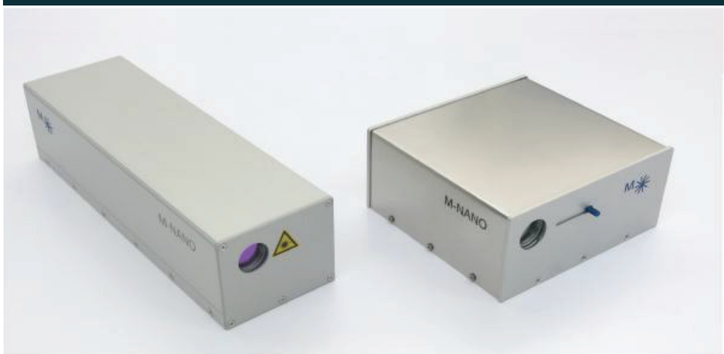
Melbourne, Australia

Bringing to you new innovative products & services

MONTFORT Laser GmbH

MONTFORT Laser is an European laser manufacturing enterprise, which produces numerous solid state lasers using state of the art technology and innovation. **Montfort** specializes on particularly compact pulsed laser sources mainly for scientific applications, such as "Photo-acoustics", beam analysis, test & measurement, defense and materials processing. Their main focus lies on nanosecond and ultrafast laser sources, customised to customer's needs for integration and applications in a limited space. **Montfort** is actively engaged in leading research and development, both triggered by customers as well as state or European programs, together with leading international research partners.

M-NANO Nano Second Q-Switched Lasers



Customized dimensions for your integration needs.

M-NANO Integrated, "All-in-one"Series- with up to 100 mJ:
Particularly compact **40-to-100-mJ-level, ~8-ns** Nd:YAG lasers with high efficiency due to diode-pumping, and excellent beam quality. these **M-NANO** laser models are **ideally suited for LIBS**, **PIV**, **LIDT, and other Spectroscopy** applications.
The driver electronics is included in the small foot print, enabling portable and battery powered application.

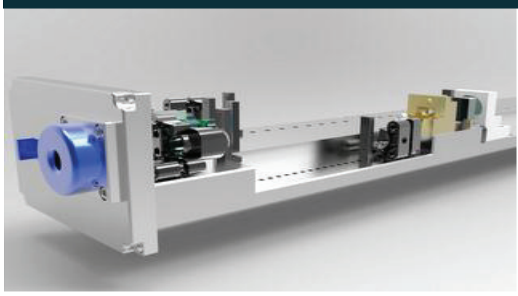
M- FEMTO And M- PICO

ULTRAFAST SPECIALITY LASERS (with SYNC option)

M-FEMTO **"soliton modelocking"** based **oscillators only - now with up to >100 W average output power, and pulses down to the sub-100-fs regime**, these femtosecond oscillator based lasers are for research applications

M-PICO **(oscillators only)** with Ytterbium or Nd:Vanadate as the host, e.g. with up to 4W @ 1-ps from a multi-Watt Yb picosecond laser oscillator.

Compact Custom DPSS Lasers, Contract R&D services



Also, Montfort expertise areas include:

- Diode-pumped Q-switched lasers with space constraints.
- Diode-pumped ultrafast solid-state laser oscillators.
- Diode-pumped ultrafast (femtosecond or picosecond) solid-state laser regenerative amplifiers.
- Frequency conversion.
- Laser resonator design and concepts.

VISIT OUR WEBSITE
www.photonscientific.com.au **or**
www.montfrontlaser.com

CONTACT US
E-mail: photon@photonscientific.com.au
phone: +61 3 85026393

Submission Of Copy:
Contributions on any topic of interest to the Australasian optics community are solicited, and should be sent to the editor, or a member of the ANZOS council.

Advertising:
Potential advertisers in ANZOS News are welcome, and should contact the editor.
Rates: Colour pages $345, Black and White pages $175, with a surchargee for choosing a specific page for the ads (rates excl. GST). 1-2 Black and White pages in the main body of the newsletter are free to corporate members.

Editor
Jessica Kvansakul
jk.aosnews@gmail.com

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

Australian and New Zealand Optical Society website:

http://www.optics.org.au

- News
- Membership
- Optics links
- Prizes/awards
- Conferences
- Jobs/Scholarships
- Affiliated societies
- ...and more

April/May 2020 Volume 34 Number 1

Articles

Departments

Cover Pictures:

- Nonlinear optical metasurfaces offer exciting new possibilities for nonlinear metadevices such as beam deflectors, sensors and metalenses. See page 27 for an overview of recent progress.
- Insets (left to right)
  - Only around two percent of the population has green eyes. Find out more about the colour of eyes on page 8.
  - Conceptual image of second-harmonic generation from a GaAs-based nanoparticle. Read more about nonlinear optical nanoparticles on page 11.
  - Wes Sandle, pioneer in laser physics and spectroscopy in New Zealand, died in February this year, see page 18.

THE AUSTRALIAN AND NEW ZEALAND OPTICAL SOCIETY

ANZOS Executive

PRESIDENT
John Harvey
Southern Photonics
Level 4, 385 Queen Street
Auckland 1010, New Zealand
Tel: +64 9 3076248
j.harvey@southernphotonics.com

VICE PRESIDENT
John Holdsworth
School of Mathematical and Physical Sciences
University of Newcastle
University Drive
Callaghan, NSW, 2308
Tel: 02 4921 5436
john.holdsworth@newcastle.edu.au

PAST PRESIDENT
Simon Fleming
School of Physics
University of Sydney
Faculty of Science
Sydney, NSW 2006
Tel: 02 9114 0851
simon.fleming@sydney.edu.au

SECRETARY
Dragomir Neshev
Nonlinear Physics Centre, RSPE
Australian National University
Canberra, ACT 2601
Tel: 02 6125 3792
dragomir.neshev@anu.edu.au

TREASURER
Arnan Mitchell
Director, Micro Nano Research Facility
RMIT University
Melbourne, VIC 3000
Tel: 03 9925 2457
arnan.mitchell@rmit.edu.au

ANZOS Councillors

Ken Baldwin
Laser Physics Centre, RSPE
Australian National University
Canberra, ACT 2601
Tel: 02 6125 4702
kenneth.baldwin@anu.edu.au

Frederique Vanholsbeeck
Department of Physics
University of Auckland
Auckland 1010, New Zealand
Tel: +64 9 923 8881
f.vanholsbeeck@auckland.ac.nz

Daniel Gomez
Department of Applied Chemistry and Environmental Science
RMIT University
Melbourne, VIC 3000
Tel: 03 9925 9015
daniel.gomez@rmit.edu.au

Irina Kabakova
School of Mathematical and Physical Sciences
University of Technology Sydney
Ultimo, NSW 2007
Tel: 02 9514 4830
irina.kabakova@uts.edu.au

Halina Rubinsztein-Dunlop
Department of Physics
University of Queensland
Brisbane, QLD 4072
Tel: 07 3365 3139
halina@physics.uq.edu.au

Heike Ebendorff-Heidepriem
Department of Physics
University of Adelaide
Adelaide, SA 5005
Tel: 08 8313 1136
heike.ebendorff@adelaide.edu.au

Michael Steel
Department of Physics and Astronomy
Macquarie University
Sydney, NSW 2109
Tel: 02 9850 8916
michael.steel@mq.edu.au

INDUSTRY REPRESENTATIVE
John Grace
Raymax Lasers
Sydney, NSW 2102
Tel:02 9979 7646
johng@raymax.com.au

Corporate Members

Coherent Scientific
Lastek
LightOptronics Aust.
Miriad Technologies
Photon Scientific
Raymax Lasers
SPIE
Warsash Scientific

President's Report

The changes that we have all experienced and witnessed in the past three months have been brought sharply into focus for me as I write this report in lockdown. As I wrote the last one, reports were coming out of Wuhan about a new coronavirus but the impacts seemed remote. Indeed, I had heard of Wuhan as a centre of optical fibre technology manufacturing in China, but this is not what it will be known for worldwide in the future. In April we are nearly all working from home, airlines have stopped flying, production of nearly everything has slowed or stopped, as nearly the whole world pushes the "pause" button. This was unthinkable when I wrote the last report.

It is unclear what the future holds for the economy but at this stage both Australia and New Zealand are containing the outbreak well, albeit at huge economic cost. Those of us working in the tertiary education sector may well find that the virus has accelerated the gradual shift in instructional modalities towards online learning into an irreversible step change. Those of us working in industry also have to accommodate big changes in both manufacturing methods and customer interactions. Whilst some workers in our sector can work from home, that is largely impossible for research workers in optics and photonics. Fortunately however, these technologies are playing a huge part in the lives of everybody through the widespread availability of high speed internet connectivity. It is hard to imagine how much more oppressive lockdown conditions would be, without the optical technologies underpinning the internet which maintains social connections and enables businesses. Photonic technologies are of course also a crucial component of coronavirus tests, which monitor the spread of the virus and will also be used to develop antibody test systems.

Of immediate importance is the issue of conference organisation. In the last report I discussed the advantages and disadvantages of the experimental joint meeting combining the SPIE and ANZCOP conferences in December in Melbourne. The issues that arose at that conference were the subject of a series of follow up meetings between SPIE and members of Council at the Photonics West conference in San Francisco in February. These meetings led to a proposal for a new way to combine the two meetings which will hopefully overcome the issues which were identified in Melbourne. The Council has proposed collocating ANZCOP with WSOF (Workshop on Speciality Optical Fibres) in Adelaide in December 2021 and the proposed collaboration with SPIE involves the two conferences (ANZCOP/WSOF and SPIE) running together at the same venue with one common day when joint sessions will be scheduled. This plan however, has been sidelined by the current COVID-19 crisis, and SPIE has been preoccupied with reorganising the many other conferences which it runs this year, which have now been turned into online conferences, cancelled, or delayed, and no formal agreement is yet in place. The organisers of the CLEO/PACRIM conference scheduled for later this year are having to make similar decisions, and we have also had discussions with the organisers of the AIP conference in December this year, with whom we had planned to collocate this year's ANZCOP meeting. It now seems likely that this AIP meeting will be deferred until December 2021, and collocated with the ANZCOP/WSOF meeting. This should ensure a good attendance even if we cannot entice too many overseas participants as it will be the one major optics related meeting and trade show in our region next year.

On a more positive note I would like to congratulate last year's award winners, not all of which were confirmed before the last edition of the AOS News. The W. H. (Beattie) Steel Medal was awarded to Professor Chennupati Jagadish of Australian National University, for his pioneering contributions to semiconductor optoelectronics and nanophotonics, the Geoff Opat Early Career Researcher Prize was jointly awarded to Dr Jiawen Li of the University of Adelaide and Dr Ke Wang, of RMIT University. The Postgraduate Student Prize was also jointly awarded to Ms Gayathri Bharathan, of Macquarie University, and to Mr Kai Wang, of Australian National University. Mr Kai Wang was also awarded the AOS/Warsash Science Communication Prize in Optics, while the John Love Award went to Dr Sergio Leon-Saval, of the University of Sydney. The deadline for nominations has been extended this year in view of the unprecedented situation that we all find ourselves in, and I would particularly like to urge members to make prompt nominations for the 2020 medals.

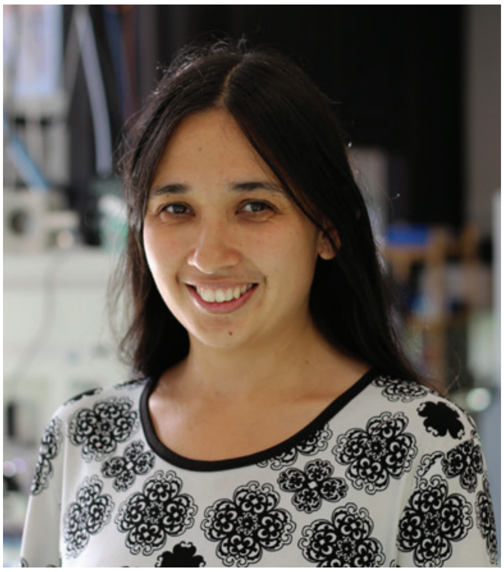
You will hopefully also have noted the new look of this magazine, which reflects the decision of the AOS council earlier this year to rename our Society as the "Australia and New Zealand Optical Society". We will retain our registration and ABN as AOS, but ANZOS is the new trading name of the Society. I was pleased to have the opportunity to announce this to an approving audience at a meeting of about fifteen of the world's Optical Societies in San Francisco, during the Photonics West Conference. The timing of this rebranding has turned out to be serendipitous, with increasing discussion of a Trans-Tasman travel bubble, and the potential for closer integration of the Research and Development work in optics, and more economic cooperation in this vitally important sector of the economy.

I would like to close with an update on the survey of the Photonics industry in our region, which was presented at the industry session of the ANZCOP meeting in December. The formal release of the report was originally planned to involve events in Canberra and Wellington this month, but the current health crisis has caused a change of plan. While gatherings in both New Zealand and Australia to mark its release are now not feasible, we anticipate having a printed and downloadable report available soon, and are now planning an electronic meeting to promote the report in the form of a webinar which is widely accessible. Whilst we cannot be sure of what the world will look like in another three months when I write the next report, we can be sure that Optics and Photonics will be crucial to its operation.

I wish all of our members good health.

John Harvey
ANZOS president

Editor's Intro



Welcome to the first issue of the rebranded ANZOS News. With the new name of the society, the magazine title has changed to reflect this and we also have a new logo. Apologies that this issue is very delayed in getting to you. The trials of Covid-19 and lockdown led to interruptions with many stages of the magazine preparation and printing processes. We are hoping to get back on track and have a great selection of articles for you. Rocio Camacho Morales was the recipient of the 2018 AOS Postgraduate Student Prize and reports on her work on nonlinear optical nanoparticles. We have an obituary of Wes Sandle, pioneer in laser physics and spectroscopy in New Zealand, who died in February. There is also a look at the colour of eyes in our 'Optics in Everyday Life' section and an article exploring nonlinear optical metasurfaces. Please send in articles if you can as we would love to hear from you.

As John has mentioned, the changes brought about in only a few months this year were hard to imagine. Like many others I struggled to juggle working from home with primary school aged children, and as someone working on a clinical trial with a vulnerable population, our research was significantly affected. There was no way that we could continue to see our patients, mainly from regional areas, so our time points for outcome measures have been stretched and are likely to be reduced. The study should still meet its main aims, but the benefit for the individuals involved may be reduced as they gained a lot from interacting with our team. This has of course allowed us time to write papers and analyse results, but it is very different working in isolation than being together in the office and lab. There will be countless other studies that have suffered interruption and may even fail to restart or be completed. Many institutions and organisations made their own decisions about which research was 'essential', with much of it paused. It has felt a little that anyone not involved in or able to switch to coronavirus-related research has been forgotten at times.

This issue includes an article summarising the report by the Australian Academy of science on the effects of Covid-19 to research. They suggest that the research workforce will be severely affected for some time with significant loss in revenue leading to job losses and reduced research capacity. There have been suggestions that women, early career researchers and recent graduates may suffer greater effects due to the interruptions this year, as they are more likely to be in less secure positions. There was an additional report on the impact of the pandemic on women in STEM. This noted the fact that women are a minority in STEM and suggests that women's careers are likely to be affected disproportionately. Some reasons for this were increases in caring responsibilities, particularly for those with children under 12, and job insecurity. There are large numbers of women on short-term contracts and in casual positions that are threatened by cuts to research income. Women are less represented at the senior levels and less likely to have secure positions. It has also been seen that there have been fewer submissions from women to journals compared to men. This is a trend that has been observed when people take parental leave, that men actually increase academic output, but it is reduced for women, and is likely to affect career advancement.

There have been some benefits for inclusion that have occurred with lockdowns across the globe, with digital technology offering people the chance to attend activities that were not possible remotely before. There have been issues as well, with those who rely on lipreading or nonverbal cues struggling with the changes that have occurred. Many have cited the usefulness of online conferences and how these can break down barriers to participation. I can see how this could be the case, but most of the useful aspects of these events are the social interaction and accidental mingling that can't be easily replicated in an online format. I have also noticed that unless an event is for Australia/New Zealand specifically, the times chosen are not very friendly for those of us based here. When you aren't actually attending a conference in person and it is in a different time zone, but you still have children at home or even just anyone else in the house, it is not at all the same or easier than attending a conference in person. I do hope that we can return to conferences in person as the norm eventually.

It remains to be seen what support there will be for the research and higher education sectors where many of our members work. Hopefully even with a reduction in the economy and fewer students there will still be a way to continue to flourish.

I hope you are doing well and that you enjoy this issue of ANZOS News.

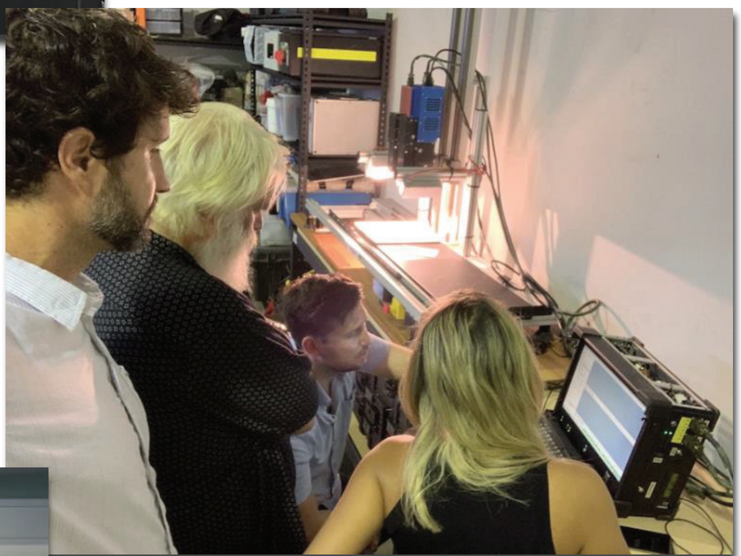
Jessica Kvansakul
Editor

HySpex
by neo

HySpex hyperspectral imaging cameras are designed to be application generic!

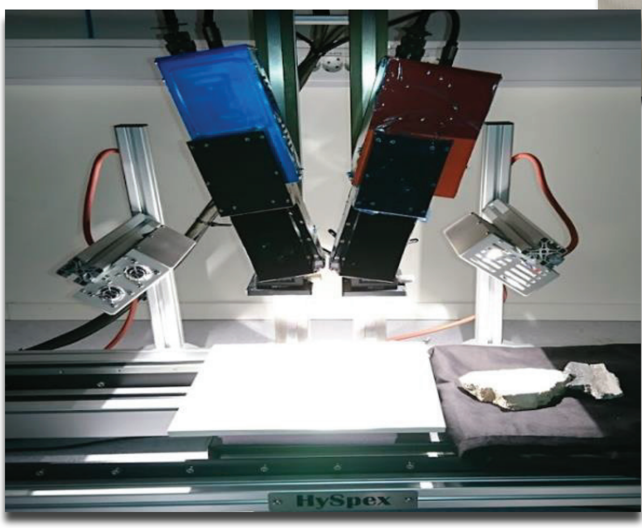
Laboratory Setup

- A scanning stage is needed to scan the cameras and build the hyperspectral data cube of the target scene.
- The scanning is automatically controlled by the data acquisition unit and based on the selected lense options.



Laboratory Training

- Setting up scanning parameters to examine geological samples
- Training in a Brisbane laboratory presented by Lukasz Paluchowski from HySpex, Norway and Dr Cédric Chaminade of Raymax



Key quality parameters of unsurpassed outcomes in hyperspectral imaging:

- Good SNR for all specified wavelengths
- Low spectral and spatial distortions per pixel and band
- Sharp optic relative to a pixel
- Low FOV optics
- Low noise floor and full well detector
- Traceable calibration
- Robust, stable and repeatable

Raymax LASERS

For more information on HySpex hypsersepctral imaging cameras
Raymax Applications Pty Ltd
t: 02 9979 7646 e: info@raymax.com.au

Optics in Everyday Life: The Colour of Eyes

by Tony Klein

By far the largest proportion of people in the world – up to 79% - have brown eyes: from light brown to dark brown to chocolate brown. This fact is simply explained by the fact that melanin, the common pigment in skin coloration, is present in various amounts in the iris.

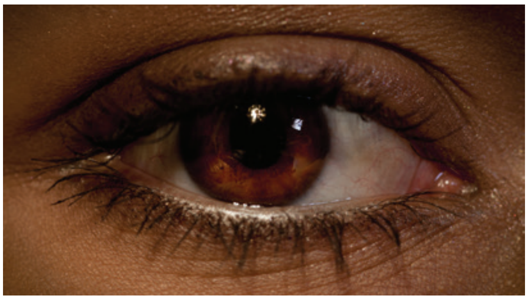


Photo by Nathan Wright from Pixabay.

But what about the second-most common eye colour possessed by 8 to 10 % of people? Surprisingly, there is no such thing as a blue pigment! The colour is entirely due to light scattering – the so-called Tyndall Effect, named after Irish Physicist John Tyndall [1] (1820-1893) who studied the phenomenon. Light is scattered by colloidal particles in air, such as smoke, or in liquids such as dilute milk, the colours depending on particle sizes: for small particles such as the ones that give rise to the blue haze in the distance in eucalypt or pine forests, or the rising column of fresh cigarette-smoke which turns grey further up as the particle sizes grow. This is exactly what happens to the fibrous structures in the iris; back-scattering the ambient daylight with a preponderance of short wavelengths – inversely proportional to the fourth power of the wavelength.

If this relation looks familiar, it is no coincidence: it's just like the Rayleigh scattering formula which explains the colour of the sky. With an important exception: Atmospheric scattering is produced by the fluctuations of the number of gaseous molecules per cubic wavelength, i.e. structures very much smaller than the ones responsible for the Tyndall scattering which, as we saw, is caused by colloidal particles much larger than the wavelength.

As is well known, most Caucasian babies are born with blue eyes. It takes several months for the melanin production to reach the iris – so one really can't tell what the eventual colour of their eyes will become. It used to be thought that brown eyes are genetically dominant, but it turns out that the genetics of eye colour is vastly more complicated and up to 16 different genes may be involved. Thus, it is rare, but not impossible, for two brown-eyed parents to have a blue-eyed baby, causing great consternation. Because of such complications, we will not pursue the genetic aspects of the problem but instead pursue the other optical effects responsible for other eye colours [3].

Photo by Amanda Dalbjörn on Unsplash.

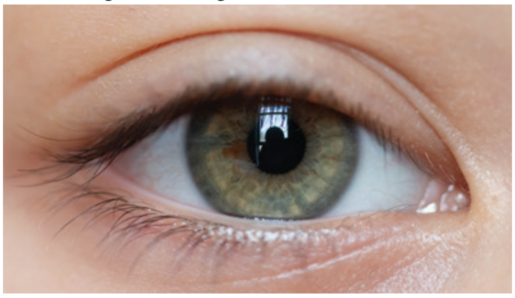
Table 1 [4] shows the other types of human eye colours, with the approximate proportion of occurrences in the world.

Rank	Eye Colour	Percentage of World
1	Brown	55% - 79%
2	Blue	8% - 10%
3	Hazel	5%
4	Amber	5%
5	Green	2%
6	Grey	<1%
7	Red/Violet	<1%
8	Heterochromia	<1%

Table 1

Hazel eyes, although quite rare, are simply a combination of very light brown and Tyndall scattering. They can appear to change from green to brown to blue depending on external lighting. Amber eyes, although quite rare in humans, are caused by the presence of a yellow pigment known as lipochrome which causes the iris to exhibit a russet/coppery tint and a yellowish golden colour that may sometimes be confused with a hazel colour. Although uncommon in humans, it is common in birds, fish and some canines.

Green eyes are some of the least common and are said to be a combination of light blue with a little melanin in the front surface of the iris. They are often found in Central, Western, and Eastern Europe. Grey eyes are even rarer and are often confused with light blue eyes. They are more common in Northern and Eastern Europe. Red and violet eyes are often associated with certain types of albinism where extremely low levels of melanin allow red blood vessels to show through. Finally, there is the rare phenomenon of heterochromia where a person exhibits two different coloured eyes that is thought to be of genetic origin.



Back to blue eyes: I came across an interesting fact: Discovered by genetics researchers at the University of Copenhagen, it appears that the majority, if not all, people with blue eyes may share a common ancestor [5]. They purport to show that a mutation around 6 to 10,000 years ago produced blue eyes, and suggest that everyone with blue eyes has the same melanin-adjusting 'switch' at the same place on their DNA. They conclude that all those with blue eyes may be descendants of a single individual.

References

[1] https://en.wikipedia.org/wiki/John_Tyndall
[2] https://en.wikipedia.org/wiki/Rayleigh_scattering
[3] https://en.wikipedia.org/wiki/Eye_color
[4] https://www.healthline.com/health/eye-health/eye-color-percentages
[5] Hans Eiberg et al. Hum Genet, **123** 177-187 (2008). https://doi.org/10.1007/s00439-007-0460-x

Emeritus Professor Tony Klein is with the School of Physics, University of Melbourne.

HÜBNER Photonics

C-WAVE

Fully automated, tunable CW laser

- IR (900 - 1,300nm)
- Blue (450 - 525nm)
- Orange (540 - 650nm)
- Mod-hop-free tuning >20GHz
- Wavelength accuracy <1MHz with AbsoluteLambda™

Coming soon C-WAVE GTR (500 - 740nm)

Atomic physics | Quantum optics | Nanophotonics
Spectroscopy | Biophotonics | Holography | Metrology

OSA The Optical Society
100 Since 1916

ONE MEMBERSHIP

Infinite Possibilities

OSA Membership is an investment in your future—with professional benefits and vital connections that can last your entire career. That's why leaders in science, engineering and industry choose The Optical Society as their professional association.

As a member, you will gain access to an unparalleled, international network and the highest-caliber research. From the latest discoveries and news to members-only events and technical groups, The Optical Society is the organization of choice for leading professionals in optics and photonics, like you.

Get started. osa.org/join

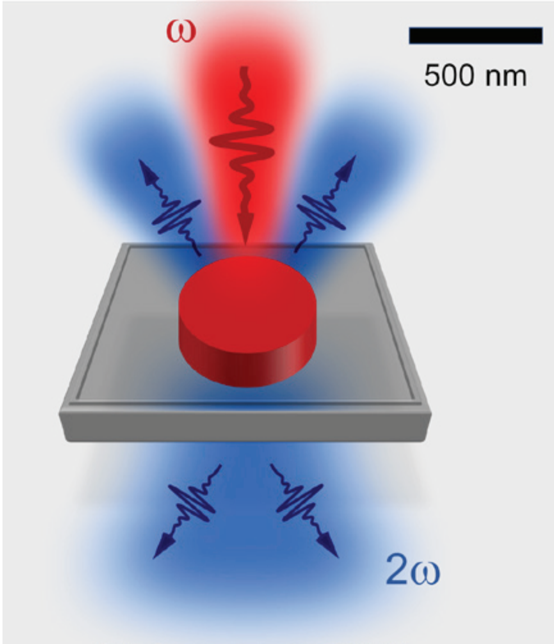
MICHAL LIPSON
Israel

ALVARO CASAS BEDOYA
Colombia

Optical Nanoparticles: Going Nonlinear

by Rocio Camacho Morales

The combination of nonlinear effects with resonant dielectric nanoparticles is motivating new research in nanophotonic applications and devices.



Conceptual image of SHG from a GaAs-based nanoparticle.

Described by the field of optical physics, light-matter interactions dominate a large part of our daily lives. Examples of these interactions include refraction, reflection, absorption and scattering of light. All these phenomena have one thing in common: they are observed when sunlight or any other light source of low intensity illuminates an object. When light of low intensity illuminates a material, the optical properties of the material do not depend on the light intensity. In this case, the observed phenomena are described by the field of linear optics. However, for strong light sources, such as those provided by lasers, new optical phenomena occur in the material, no longer described via the linear optical regime. Nonlinear optics characterises the optical phenomena produced by strong light sources, where the optical properties of the material are modified by the presence of light. Although nonlinear effects were recognised since Maxwell's time, progress in this field was delayed until the development of lasers, first proven by Maiman in 1960. Ever since, nonlinear optics has played an important role in the development of photonic science and technologies. The applications of nonlinear optics vary from light sources, quantum optics, signal processing, optical communications, bioimaging, spectroscopy, ultra-cold atoms and plasma physics, to name a few.

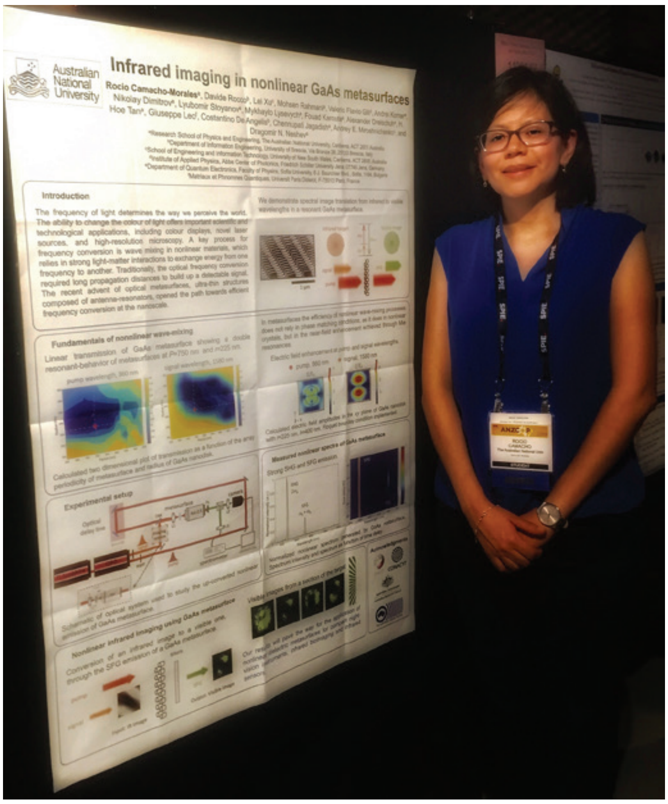
Parametric nonlinear processes are key in the development of nonlinear photonic applications, due to their capability to change the frequency of the incident light conserving the energy of the system. In a parametric nonlinear process, the incident photons interact with each other inside the material, generating new photons of higher (upconversion) or lower (downconversion) frequency than the incident photons. Second and third order nonlinear processes are the most important for frequency conversion. Second-order or quadratic nonlinear processes, including second-harmonic generation (SHG) and sum-frequency generation (SFG), are only produced in non-centrosymmetric media. With an intrinsic lower conversion efficiency, third-order or cubic nonlinear processes, including third-harmonic generation (THG) and four-wave mixing (FWM), are not limited to specific materials. Frequency conversion has been widely studied in bulk nonlinear crystals, where the phase-matching condition limits the conversion efficiency. The phase-matching condition ensures all propagating fields travel with the same phase velocity along the crystal length, allowing constructive interference of the nonlinear fields, while the phase mismatch prevents the constructive addition of the fields.

Recently, significant scientific efforts have been made to miniaturise nonlinear optical configurations. This research has led to the development of nonlinear optical nanoparticles, facilitated by significant advancements in nanofabrication techniques. In nanoparticles, the light-matter interaction takes place in subwavelength volumes. As a consequence, efficient frequency conversion in nanoparticles is no longer limited by the phase-matching condition, as is the case when using bulk nonlinear crystals. However, the reduction of light-matter interactions to subwavelength volumes also decreases the intensity of the new frequencies generated. By designing resonant nanoparticles, according to the theory developed by Gustave Mie in 1908 [1], this problem can be solved. Since nonlinear processes scale with high powers of the local field, the enhanced incident field produced inside the nanoparticles as a result of the resonant condition yields an increased conversion efficiency.

The study of frequency conversion processes in resonant nanoparticles was first performed in metallic, also called plasmonic, materials [2]. Inherent to plasmonic materials are Ohmic losses, originated by the complex conductivity of metals. Ohmic losses and detrimental heating have limited the possible applications of plasmonic nanoparticles. Dielectric nanoparticles have emerged as a promising alternative to plasmonic ones, due to their low losses and the possibility to excite the multipole electric and magnetic Mie resonant modes [3, 4]. Silicon (Si) possesses a strong cubic optical nonlinearity, together with a moderately high refractive index, both beneficial in the design of resonant nanoparticles for nonlinear optics. Enhanced THG has been shown in Si nanoparticles, attributed to the excitation of magnetic resonances [5, 6]. Moreover, the THG emission from Si nanoparticles can be manipulated to specific directions by employing the properties of higher-order multipole resonances [7]. Although Si nanoparticles have been widely used in the study of THG, second-order nonlinear processes have not been extensively explored in these nanoparticles due to the centrosymmetric crystalline structure of Si. Gallium Arsenide (GaAs) is a non-centrosymmetric material with a high quadratic optical nonlinearity. Thus, GaAs-based nanoparticles have been used to study SHG, reporting high conversion efficiencies [8, 9]. Control over the SHG properties of GaAs-based nanoparticles has been demonstrated, including directionality [10, 11], polarisation [12] and angular distribution [13].

However, applications often require field enhancements beyond the ones obtained from single resonant nanoparticles. Metasurfaces are ultrathin planar systems formed by close packing of resonant nanoparticles, exhibiting unusual characteristics due to the collective response of their constituent components. This collective response makes metasurfaces a suitable platform for nonlinear nanophotonic applications. Wavefront engineering of THG fields has been demonstrated in Si metasurfaces, achieving nonlinear beam deflectors and nonlinear vortex beam generations [14]. Also, nonlinear wavefront control has been used in Si metasurfaces to encode phase gradients and holographic images in the THG, demonstrating holographic multiplexing [15]. On the other hand, GaAs-based metasurfaces have been used to demonstrate an optical frequency mixer that concurrently generates eleven new frequencies spanning from the ultraviolet to near-infrared [16].

At ANU, we have been exploring a novel application of GaAs metasurfaces for infrared (IR) imaging. Conventional IR detectors are divided into two categories, namely photon and thermal detectors. Both detectors are limited by their sensitivity, response time or noise performance. Nonlinear optics provides an alternative mechanism to detect IR radiation. In 1968, J. E. Midwinter first demonstrated parametric upconversion imaging from the near-IR to the visible spectrum, using a bulk nonlinear crystal [17]. In his work, Midwinter successfully transferred the spatial and spectral information from the IR to the visible spectrum, thus providing an alternative mechanism to detect IR images using standard detectors. In contrast, we have demonstrated IR imaging based on frequency-mixing of an IR image with a pump beam, using a resonant GaAs metasurface. Through the frequency-mixing process, or more specifically through the SFG process, visible images were achieved which can be detected by a conventional complementary metal-oxide-semiconductor (CMOS) sensor. With our approach, practical IR imaging can be achieved even with a weak IR light source, using resonant metasurfaces and pump beam laser assistance. Our results open up new opportunities for the development of compact night-vision devices operating at room temperature, with multiple applications in defence and life sciences applications [18].



Rocio Camacho presenting her work at the 2019 ANZCOP Conference.

This work, titled Infrared imaging by nonlinear metasurfaces, was presented at the 2019 ANZCOP Conference held in Melbourne, from 8th to 12th of December.

Acknowledgements

I would like to thank the Australian Optical Society for awarding me the Postgraduate Student Prize and supporting my participation in the 2019 ANZCOP Conference, where I presented my work on Infrared imaging using nonlinear resonant GaAs metasurfaces [18].

References

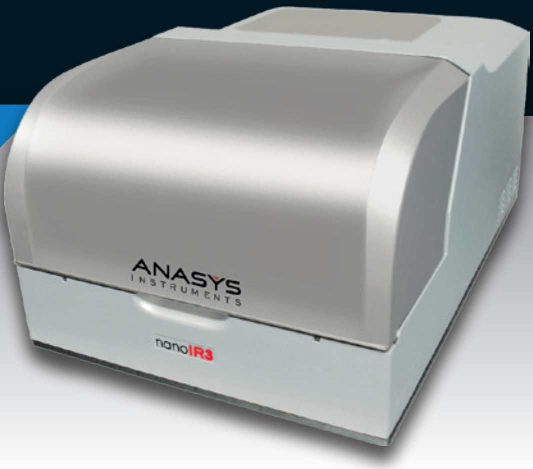
[1] G Mie, Ann. Phys. **330**, 337 (1908).
[2] SB Hasan et al., Materials Today **17**, 478 (2014).
[3] AB Evlyukhin et al., Nano Lett. **12**, 3749 (2012).
[4] AI Kuznetsov et al., Sci. Rep. **2**, 492 (2012).
[5] MR Shcherbakov et al., Nano Lett. **14**, 6488 (2014).
[6] EV Melik-Gaykazyan et al., Phil. Trans. R. Soc. A **375**, 20160281 (2017).
[7] DA Smirnova et al., ACS Photon. **3**, 1468 (2016).
[8] L Carletti et al., Opt. Express **23**, 26544 (2015).
[9] VF Gili et al., Opt. Express **24**, 15965 (2016).
[10] R Camacho-Morales et. al., Nano Lett. **16**, 7191 (2016).
[11] L Xu et. al, ACS Nano **14**, 1379 (2020).
[12] L Ghirardini et al., Opt. Lett. **42**, 559 (2017).
[13] L Carletti et al., ACS Photonics **5**, 4386 (2018).
[14] L Wang et al., Nano Lett. **18**, 3978 (2018).
[15] B Reineke et al., Nano Lett. **19**, 6585 (2019).
[16] S Liu et al., Nature Communications **9**, 2507 (2018).
[17] JE Midwinter et al., Appl. Phys. Lett. **12**, 68 (1968).
[18] R Camacho-Morales et al., SPIE Micro + Nano Materials, Devices, and Applications 2019, 112011S (2019).

Rocio Camacho Morales is with the Nonlinear Physics Centre, ANU, and was the recipient of the 2018 AOS Postgraduate Student Prize.

BRUKER

Surface & Dimensional Analysis

NEW



Nanoscale IR Spectroscopy nanoIR3

Tapping AFM-IR for sub-10nm chemical imaging resolution

Highest performance nanoscale FTIR spectra

Nanoscale material property mapping

Matches industry FTIR databases

Tribology

Comprehensive materials tester for mechanical and tribological properties

Nanoindentation

Nanoscale and microscale mechanical and tribological characterisation

Optical Profiling

High-resolution non-contact measurement tool

High-resolution AFM Microscopes

Large sample and small sample atomic force microscopes

(08) 8150 5200
sales@coherent.com.au
www.coherent.com.au

Coherent SCIENTIFIC

Amplitude

SYSTEMES

Amplitude's intense lasers PULSAR and ARCO have been designed to serve the needs of most challenging applications!

- Modern laser sources routinely achieve intensities as high as 10^{22} W/cm². With such intensities, Ultra-intense laser systems have accelerated the advent of new physics with significant applications in fundamental science, medical research and industry.

- By focusing ultrashort intense laser beams onto targets, extremely high electric fields with strength higher than 1 TV/m have been produced. Hence, energetic particles such as electrons, protons and ions, as well as radiation ranging from X-ray to γ-ray, can be delivered using the appropriate targets like gas jets, thin metallic foils or capillaries. These outstanding properties, such as pulse width or brightness, laser-driven particles and radiation forms ably demonstrate their uniqueness compared to conventional sources.

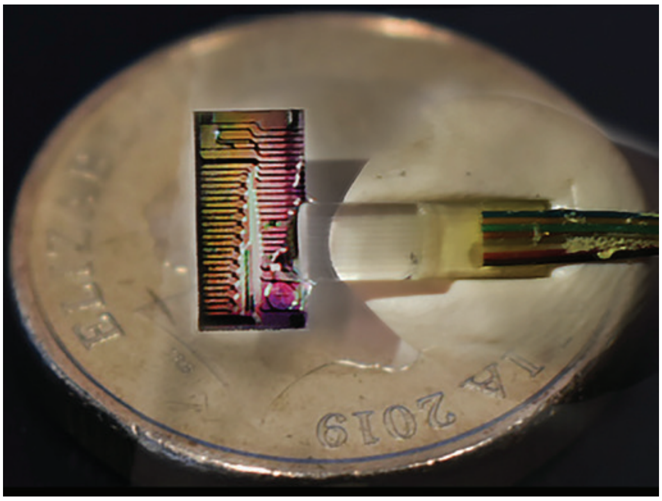
Raymax LASERS

For more information on Amplitude systems and recent developments contact
Raymax Applications Pty Ltd
t: 02 9979 7646   e: info@raymax.com.au

Australasian Research in the News

World's fastest internet speed from a single optical chip

Researchers from Monash, Swinburne and RMIT universities have successfully tested and recorded Australia's fastest internet data speed, and that of the world, from a single optical chip – capable of downloading 1000 high definition movies in a split second. Published in the journal Nature Communications, these findings have the potential to not only fast-track the next 25 years of Australia's telecommunications capacity, but also the possibility for this home-grown technology to be rolled out across the world.



Researchers from Monash, Swinburne and RMIT universities have recorded the world's fastest internet speed from a single optical chip of 44.2 Terabits per second.

In light of the pressures being placed on the world's internet infrastructure, recently highlighted by isolation policies as a result of COVID-19, the research team led by Dr Bill Corcoran (Monash), Distinguished Professor Arnan Mitchell (RMIT) and Professor David Moss (Swinburne) were able to achieve a data speed of 44.2 Terabits per second (Tbps) from a single light source. This technology has the capacity to support the high-speed internet connections of 1.8 million households in Melbourne, Australia, at the same time, and billions across the world during peak periods.

Demonstrations of this magnitude are usually confined to a laboratory. But, for this study, researchers achieved these quick speeds using existing communications infrastructure where they were able to efficiently load-test the network. They used a new device that replaces 80 lasers with one single piece of equipment known as a micro-comb, which is smaller and lighter than existing telecommunications hardware. It was planted into and load-tested using existing infrastructure, which mirrors that used by the NBN. It is the first time any micro-comb has been used in a field trial and possesses the highest amount of data produced from a single optical chip.

"We're currently getting a sneak-peak of how the infrastructure for the internet will hold up in two to three years' time, due to the unprecedented number of people using the internet for remote work, socialising and streaming. It's really showing us that we need to be able to scale the capacity of our internet connections," said Dr Bill Corcoran, co-lead author of the study and Lecturer in Electrical and Computer Systems Engineering at Monash University. "What our research demonstrates is the ability for fibres that we already have in the ground, thanks to the NBN project, to be the backbone of communications networks now and in the future. We've developed something that is scalable to meet future needs. And it's not just Netflix we're talking about here – it's the broader scale of what we use our communication networks for. This data can be used for self-driving cars and future transportation and it can help the medicine, education, finance and e-commerce industries, as well as enable us to read with our grandchildren from kilometres away."

To illustrate the impact optical micro-combs have on optimising communication systems, researchers installed 76.6km of 'dark' optical fibres between RMIT's Melbourne City Campus and Monash University's Clayton Campus. The optical fibres were provided by Australia's Academic Research Network. Within these fibres, researchers placed the micro-comb – contributed by Swinburne University, as part of a broad international collaboration – which acts like a rainbow made up of hundreds of high quality infrared lasers from a single chip. Each 'laser' has the capacity to be used as a separate communications channel. Researchers were able to send maximum data down each channel, simulating peak internet usage, across 4THz of bandwidth.

Distinguished Professor Mitchell said reaching the optimum data speed of 44.2 Tbps showed the potential of existing Australian infrastructure. The future ambition of the project is to scale up the current transmitters from hundreds of gigabytes per second towards tens of terabytes per second without increasing size, weight or cost. "Long-term, we hope to create integrated photonic chips that could enable this sort of data rate to be achieved across existing optical fibre links with minimal cost," Distinguished Professor Mitchell said. "Initially, these would be attractive for ultra-high speed communications between data centres. However, we could imagine this technology becoming sufficiently low cost and compact that it could be deployed for commercial use by the general public in cities across the world."

Professor Moss, Director of the Optical Sciences Centre at Swinburne University, said: "In the 10 years since I co-invented micro-comb chips, they have become an enormously important field of research. "It is truly exciting to see their capability in ultra-high bandwidth fibre optic telecommunications coming to fruition. This work represents a world-record for bandwidth down a single optical fibre from a single chip source, and represents an enormous breakthrough for part of the network which does the heaviest lifting. Micro-combs offer enormous promise for us to meet the world's insatiable demand for bandwidth."

Source material: https://www.monash.edu/news/articles/australian-researchers-record-worlds-fastest-internet-speed-from-a-single-optical-chip

Original article: Bill Corcoran, Mengxi Tan, Xingyuan Xu, Andreas Boes, Jiayang Wu, Thach G. Nguyen, Sai T. Chu, Brent E. Little, Roberto Morandotti, Arnan Mitchell, David J. Moss. *Ultra-dense optical data transmission over standard fibre with a single chip source*. Nature Communications, 2020 11 (1). https://doi.org/10.1038/s41467-020-16265-x

Light, sound, action: extending the life of acoustic waves on microchips

Scientists in Australia and Europe have taken an important step towards removing 'hot' electrons from the data chips that are a driving force in global telecommunications. Microchips without electrons will allow for the invention of data processing systems that don't overheat, have low energy costs and reduce greenhouse gas emissions. Researchers from the University of Sydney Nano Institute and Max Planck Institute for the Science of Light say that chips using light and sound, rather than electricity, will be important for the development of future tech, such as high-speed internet as well as radar and sensor technology. This will require the low-heat, fast transmission of information.

"As demand for high bandwidth information systems increase, we want to get ahead of the curve to ensure we can invent devices that don't overheat, have low energy costs and reduce the emission of greenhouse gases," said Dr Moritz Merklein from the Eggleton Research Group in the School of Physics and Sydney Nano. The idea is to use sound waves, known as phonons, to store and transfer information that chips receive from fibre-optic cables. This allows the chips to operate without needing electrons, which produce heat. The team was the first in the world to successfully manage this process on chip. However, information transferred from fibre-optic cables onto chips in the form of sound waves decays in nanoseconds, which is not long enough to do anything useful.

"What we have done is use carefully timed synchronised pulses of light to reinforce the sound waves on-chip," said Dr Birgit Stiller, who has moved from the University of Sydney to lead an independent research group at the Max Planck Institute for the Science of Light in Germany. "We have shown for the first time that refreshing these phonons is possible and that information can therefore be stored and processed for a much longer time," she said. The scientists carefully timed pulses of light to extend the lifetime of the information stored in sound waves on the chip by 300 percent, from 10 nanoseconds to 40 nanoseconds.

The research, published in the journal Optica, was done in collaboration with the Laser Physics Centre at the Australian National University and the Centre for Nano Optics at the University of Southern Denmark. "We plan to use this method to extend how long the information remains on-chip," said Dr Merklein, also from the Institute of Photonics and Optical Science at the University of Sydney. Dr Stiller said: "Acoustic waves on chips are a promising way to store and transfer information. "So far, such storage was fundamentally limited by the lifetime of the sound waves. Refreshing the acoustic waves allows us to overcome this constraint."

Associate Professor Christian Wolff, a project collaborator from the University of Southern Denmark, said: "Theoretically, this concept can be extended to the microsecond regime." This proof-of-principle demonstration opens many possibilities for optical signal processing, fine filtering, high-precision sensing and telecommunications.

Source material: https://www.sydney.edu.au/news-opinion/news/2020/05/07/light-sound-action-extending-life-acoustic-waves-on-phonon-photonic-microchips.html

Original article: Birgit Stiller, Moritz Merklein, Christian Wolff, Khu Vu, Pan Ma, Stephen J. Madden, Benjamin J. Eggleton. *Coherently refreshing hypersonic phonons for light storage*. Optica, 2020; 7 (5): 492 DOI: 10.1364/OPTICA.386535

ANZOS Image Competition

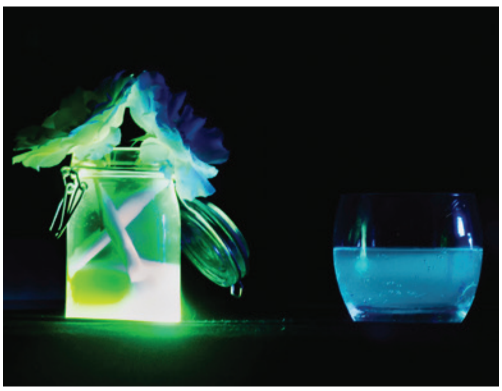
Help us demonstrate the beauty of optics and photonics

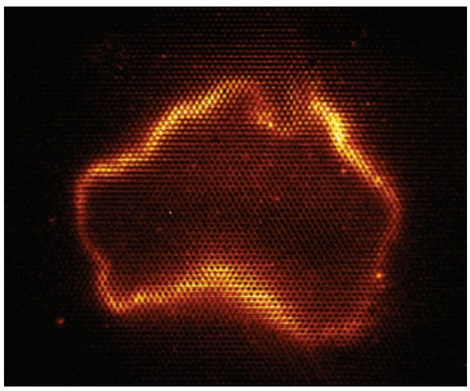
We want your assistance in generating photographs that we can use to promote Australian and New Zealand optics and photonics in print and online. We will publish the best photograph on the front cover of ANZOS News, and whoever submits this will get a year's membership free. Please submit photographs or images that capture some aspects of optics and photonics, and are aesthetically pleasing. They can, for instance, be of your research, of optical phenomena, of optical devices.

The photos will be judged by a panel including three ANZOS Councillors, the Editor of the ANZOS News and the ANZOS Webmaster. The competition will continue on an approximately quarterly basis with judging for each issue of ANZOS News. ANZOS will carry forward high scoring entries from one round to the next. The ANZOS reserves the right in any particular round to award multiple winners or to award no winner. A person may only win once in each calendar year. The competition will run until end of 2022. ANZOS may extend this date or terminate earlier, advising by email, through ANZOS News, or other reasonable communication.

Queries to ausoptsoc@gmail.com

Some of our past winners are pictured here. Left: Ice bow, by Stephane Coen, University of Auckland. Middle: Phosphorescence, by Krzysztof Maliszewski. Right: Topological Australia, by Sergey Kruk, Australian National University.





Photonic Professional GT2

The world's highest resolution 3D printer

Nanoscribe Photonic Professional GT2 uses Two-Photon Polymerization (2PP) to produce filigree structures of nearly any 3D shape. Flexibility in design combined with straightforward operation and a wide range of materials and substrates make the Photonic Professional GT2 an ideal instrument for science and prototyping in multi-user facilities and research laboratories.

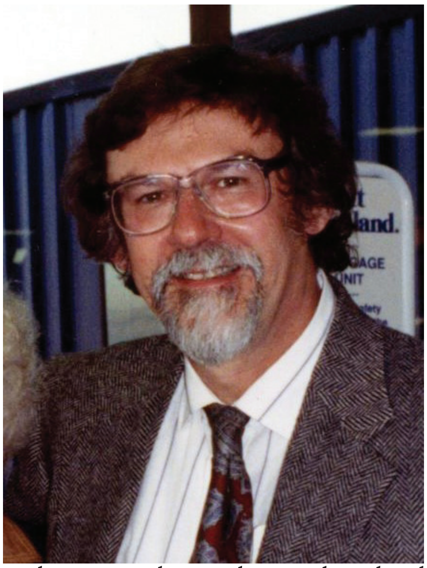
DESIGNED FOR RESEARCH AND RAPID PROTOTYPING IN

- Microfluidics
- Micromechanics
- Biomedical engineering
- Micro-electromechanical systems
- Mechanical metamaterials
- Photonic metamaterials and plasmonics
- Microoptics
- Nanostructures

Weston James Sandle 1935 - 2020

ONZM, MSc NZ, PhD Berkeley, FRSNZ

by Gerry Carrington and Rob Ballagh, with contributions from Tony and Alison Sandle



Wes Sandle died in February 2020 after a period of ill health. He was a pioneer in New Zealand in laser physics and laser spectroscopy, admired for his intellect and vision and warmly remembered by his colleagues and research students for his unwavering generosity, support and friendship.

Wes earned international respect in the atomic physics and laser community, and was influential to a young generation of Australian physicists in this field. Bringing a deep insight to physical problems, and the drive to keep abreast of major new directions, he carried out his research with passion and rigour. He had great enthusiasm for physics and science in general and made influential contributions to a number of innovations in energy efficiency and energy management in New Zealand.

Wes was born in Christchurch on 19 March 1935. Growing up in New Brighton, his youth was characterised principally by his scholastic achievements and his aptitude for sport. He attended New Brighton Normal School, where he was not only the brightest pupil but also the fastest runner. He went on to Christchurch Boys' High School in 1949, leaving after the Lower Sixth in 1952 having won a New Zealand National Scholarship.

Thus armed, he began studying at Canterbury College (University of New Zealand) in 1953. After finishing a BSc, he was awarded the George Grey Memorial prize and completed an MSc with first class Honours in Mathematics in 1957. In 1958 he was awarded a King George VI Memorial Fellowship supporting postgraduate study abroad, and he entered the PhD programme in physics at Berkeley, University of California. His time in California had a profound influence on both his professional and personal life. The Berkeley Physics Department had many outstanding professors, including household names such as Edward Teller, and Wes was inspired by their elegant approach to physics. He chose to work on the application of NMR to solid-state physics under the supervision of Alan Portis. In the summer of 1963 Wes met Pat Tisdel from Colorado, whom he married three months later in Berkeley. Together they raised two children, Alison and Tony.

Newly married and with graduate funding running out, Wes made the decision to suspend his PhD study in 1963 and accept the position of Lecturer in Physics at Otago University, which was then undergoing a period of reinvigoration. His interests aligned most strongly with Jack Dodd's atomic physics group, and he enthusiastically joined their research programme on quantum beats in resonance fluorescence. At that time, the range of atomic species and transitions accessible to their experimental techniques was limited. Wes, using insights from his solid-state background, developed a novel experimental approach employing pulsed magnetic fields, which significantly widened that range. Together with a series of graduate students, he took a lead role in the first demonstrations of quantum beats induced by pulsed magnetic and electric fields and their application to the measurement of atomic coherence and collision lifetimes. In the meantime, his PhD thesis remained incomplete, but in 1968 as the final cut-off date loomed, Wes entered into a period of solitary and intense activity, emerging after three months with a completed thesis. His ability to sustain periods of strenuous intellectual activity under severe time pressures became familiar to his colleagues over his career.

Wes continued working in traditional atomic spectroscopy into the 1970s, publishing jointly with his graduate students and colleagues, but the advent of tuneable dye lasers ushered in a paradigm change for atomic physics. He took a major leap in 1972 establishing New Zealand's first laser physics group, which he led until his retirement in 2001, and achieved international recognition. With input from Dan Walls at Waikato University, Wes chose to work in the area of nonlinear optical effects in atomic vapours. His experimental results in optical bistability and polarisation switching beginning in 1978 received international attention. Further work followed in self-focussing, and spatial pattern formation of laser beams, and switching dynamics in Raman lasing. He established a significant international profile in the field, and built up the Otago group by obtaining funding for a modern laser laboratory, and attracting postdoctoral fellows and graduate students. In 1985 he was a Visiting Fellow at JILA, University of Colorado and a Guest Scientist at the Max Planck Institute for Quantum Optics in Garching. He served on the programme committee for the International Quantum Electronics Conference (IQEC) from 1988 to 1994 and was a foundation member of the Australasian Council on Quantum Electronics, serving from 1988 to 1996. Also, in 1998, he served as Chair for the Australasian Conference on Lasers, Optics and Spectroscopy (ACOLS), which he brought to New Zealand for the first time.

Wes was motivated by the oil crises of the 1970s to become actively involved in a number of technological innovations relevant to energy issues in New Zealand. Starting in 1977, he chaired the Energy Subcommittee of Ecology Action (Otago) which made a notable submission, "What, Nuclear Power in New Zealand?", to the Royal Commission on Nuclear Power Generation in New Zealand (1978). The Commission reported that "the use of heat pumps was strongly advocated in the Ecology Action (Otago) submission" for providing home heating with improved energy efficiency. Decades later Wes was pleased to witness the potential of heat pumps being realised, as they became widely used in New Zealand homes, driven by reduced costs, improved efficiency and the rising price of alternatives.

During the period 1979 – 85 Wes supported Gerry Carrington to secure funding from the New Zealand Energy Research and Development Committee to demonstrate the application of heat pumps for domestic space and water heating and for industrial applications. He also had an active role in the development of improved energy management processes and technologies for the University of Otago, with early initiatives achieving pay-back times of less than five months. Once this programme was established, it was entrusted to an independent Energy Management unit that was subsequently commercialised to become New Zealand's most prominent firm in this field for many years.

In the late 1980s, Wes undertook another major change in research direction, pioneering laser cooling in New Zealand. The Otago group was thus well positioned for the huge upsurge of interest in cold atom physics that followed the creation of an atomic Bose-Einstein condensate in 1995. Wes embraced the formidable challenges of creating a condensate in New Zealand, and together with Andrew Wilson, he initiated the Otago experimental programme on cold atoms and Bose-Einstein condensation. Andrew led the laboratory team, and Wes had a major role in obtaining funding, and providing supportive mentoring and guidance. In 1998 the team produced the first condensate outside a small handful of US and European labs. This success placed the Otago group firmly on the international map and laid the foundations for the current high-profile atomic physics group at Otago that has had a central role in the formation and success of the Dodd-Walls national Centre for Research Excellence.

Wes was a collegial and loyal staff member of the University of Otago and chaired the Physics department from 1993 until 1996. He was very committed to his teaching, and an enthusiastic and colourful lecturer who could transmit that enthusiasm and motivate students. He was a strong supporter of the New Zealand Institute of Physics, being a Fellow from 1983, and served in a number of roles, including Council member from 1990 and President from 1996 to 1998. He became a Fellow of the Royal Society of New Zealand in 1998 and in 2004 was appointed an Officer of the New Zealand Order of Merit, for services to science.

In retirement Wes served on both the Otago University Chaplaincy Trust Board and the Hearing Association. He was passionate about music, participating in several choirs. He continued to indulge his enduring love of technology, amassing an impressive collection of electric vehicles. Even to those in Dunedin who had never heard of him he was well known in his later years as "the elderly gent on the red electric trike". More broadly, Wes has created an enduring academic legacy through his published work, and through the careers of the students and colleagues that he mentored and encouraged throughout his life.

Gerry Carrington is an Emeritus Professor at the University of Otago, a Fellow of the Royal Society of New Zealand and a Fellow of the Institution of Professional Engineers of New Zealand. Professor Rob Ballagh is with the Department of Physics, University of Otago and is a Fellow of the Royal Society of New Zealand.

Product News

V-610 compact PIMag rotation stage

Physik Instrumente, a global leader in the design and manufacture of high precision motion control systems has launched the V-610 compact PIMag rotation stage.

The PIMag 3-phase magnetic direct drives do not use mechanical components in the drivetrain, they transmit the drive force to the motion platform directly and without friction. The drives reach high velocities and accelerations. Ironless motors are particularly suitable for positioning tasks with the highest demands on precision because there is no undesirable interaction with the permanent magnets. This allows smooth running even at the lowest velocities and at the same time, there is no vibration at high velocities. Nonlinearity in control behaviour is avoided and any position can be controlled easily. The drive force can be set freely.

Enhanced spectral purity 785nm laser for Raman

HÜBNER Photonics proudly introduces the 08-NLDM 785 nm ESP (enhanced spectral purity) as part of the Cobolt 08-01 Series. The 08-NLDM 785 nm ESP complements the Cobolt 08-01 Series of compact high-performance single frequency and narrow linewidth lasers covering a broad range of 405 nm – 1064 nm for the high resolution Raman market. Enhanced spectral purity is a desired performance specification especially for low frequency Raman applications and defines how well the side modes are suppressed relative to the main laser peak (SMSR) and how close to the main peak the level of side mode suppression is. Thanks to a patent-pending optical design the spectral purity of the 08-NLDM 785 nm ESP is >60 dB as close as 0.3 nm away from the main peak. The multi-transverse mode laser has an output power of <400 mW with fully integrated electronics in a single compact package

All Cobolt lasers are manufactured using proprietary HTCure™ technology and the resulting compact hermetically sealed package provides a very high level of immunity to varying environmental conditions along with exceptional reliability. With demonstrated lifetime capability of >60 000 hours and several thousand units installed in the field, Cobolt lasers have proven to deliver unmatched reliability and performance both in laboratory and industrial environments and are offered with market leading warranty terms.

Combined laser diode and temperature controllers

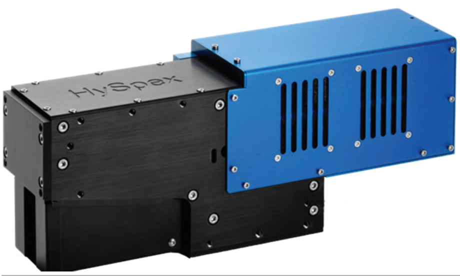
The LDTC LAB series instruments, from Wavelength Electronics, combine best-in-class low noise, high-end digital control laser diode driver technology with an IntelliTune® smart temperature controller. If you need stable wavelength, stable temperature, stable laser diode current or power, or low noise, these offer the best performance and value.

Two models are available, the LD2TC5 LAB and the LD5TC10 LAB. The LD2TC5 LAB outputs up to 2 and 5 A for the laser and thermoelectric, respectively. The LD5TC10 LAB outputs up to 5 and 10 A. Both models offer 10 V of laser compliance voltage and 15 V of thermoelectric compliance voltage.

The intuitive touchscreen interface and IntelliTune® PID control algorithm simplify precision operation.

For more information, contact Warsash Scientific at sales@warsash.com.au or 02 9319 0122

HySpex VNIR-3000 N hyperspectral camera — NEW



HySpex VNIR-3000 N utilizes the same spectrograph as the other classical HySpex VNIR models. With a pixel size of 3.45μm, compared to 6. 5μm for VNIR-1800, HySpex VNIR-3000 N will have less than 1.6 pixels per FWHM of the PSF spatially and less than 1.8 bands spectrally, ensuring that narrow band features will be resolved equally for all cameras. With 3000 spatial pixels, 300 bands and a noise floor of 2.4e-, HySpex VNIR-3000N will provide outstanding SNR levels in dark environments.

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

HySpex SWIR-384 hyperspectral camera

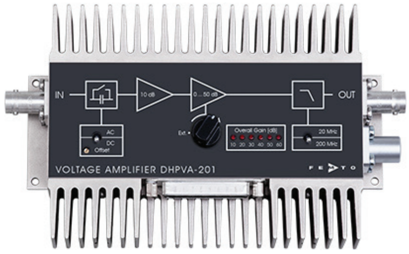
The state of the art MCT sensor with cooling down to 150K yields low background noise, high dynamic range, and exceptional SNR levels. With a max frame rate of 400 fps, combined with an aberration-corrected optical system with high optical throughput (f/2), the data quality, speed, and sensitivity is 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 centimetres with a spatial resolution of 53 μm to infinity.

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

Femto Amplifier and Photoreceiver Solutions

FEMTO offers a wide range of amplifier and photoreceiver solutions for scientific and industrial applications. The innovative amplifiers are designed for instant use in scientific and industrial applications. The noise performance and the frequency response are outstanding.



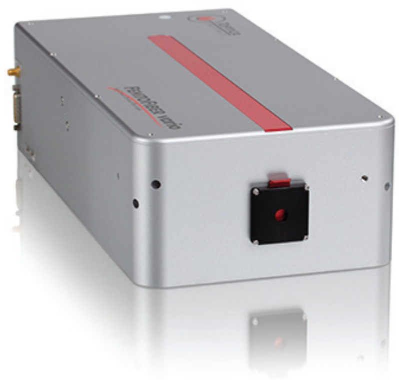
TOPTICA Photonics presents the new FemtoFiber vario 1030, a versatile micro-joule fibre laser

With a centre wavelength of 1030 nm, the laser offers 2 W of output power at a repetition rate of up to 1MHz and a pulse duration of <300 fs. The special features of this laser include variable pulse duration via GDD control, adjustable repetition rate down to pulse-on-demand, and its superior temporal and spatial beam quality.

High Power Ultrafast Fibre Lasers with superior temporal and spatial beam quality.

- Versatile micro-Joule fibre laser
- Superior temporal and spatial beam quality
- Adjustable repetition rate
- Pulse on demand
- Continuously adjustable pulse duration
- Industrial grade, compact design
- Passively-cooled, detachable laser head
- Robust and reliable, all-PM fibre setup
- Turnkey system, compact footprint

One of the main benefits for the user is the unique pulse-on-demand design that is provided with the laser. Unlike any other fibre-laser technology, the unique pulse-on-demand realisation of the FemtoFiber vario 1030 allows the user to pick the emitted pulses directly from the fundamental pulse train of the oscillator.



SIOS: Laser Vibrometers for high precise measurement of vibrations and length

The design of these devices is based on the proven concept with our SP-series miniature interferometer. The sensor head of the vibrometer is equipped with additional optics, which enables measurements on surfaces of any roughness.

Benefits:

- Displacement measurements in the frequency range 0 – 5 MHz
- Measurements through narrow windows are possible
- Vibration measurement software for Windows

Applications: High precise measurement of vibrations and length.

For more information please contact Lastek at sales@lastek.com.au or 08 8443 8668

Quantel Lumibird releases high energy pulsed Nd:YAG laser

The new Q-smart 1200 & 1500 are amplified Nd:YAG lasers that deliver up to 1.5J/pulse at 1064nm with excellent beam quality and stability.

Using the field-proven Q-smart technology, they feature plug and play temperature controlled harmonic generators (with automatic phase-matching) so the user has easy access to 1064nm, 532nm 355nm and 266nm. 213nm is available on request.

- High energy packaged into a small footprint
- 1064nm, 532nm, 355nm, 266nm
- Excellent beam quality
- Field-proven Q-smart reliability
- Plug and play harmonic generators
- SLM option available for 0.005cm^{-1} linewidth

For further information please contact Jeshua Graham, sales@coherent.com.au

Large field of view, deep cooled back-illuminated sCMOS camera for Astronomy and Physical Sciences

The new Marana 4.2B-6 back-illuminated sCMOS camera offers 95% quantum efficiency and vacuum cooling down to -45°C, combining the highest sCMOS sensitivity with high frame rates.

Marana 4.2B-6 delivers up to 74fps, perfectly suited to dynamic imaging or spectroscopic applications, such as wavefront sensing, lucky/speckle imaging, quantum gas dynamics or hyperspectral imaging.

The new camera has a 4.2 Megapixel array format with 6.5µm pixels. The smaller pixel size is better suited to resolution matching in many imaging configurations, as well as high resolution echelle spectroscopy. Low readout noise and Andor's innovative UltraVac™ vacuum cooling make Marana the most sensitive back-illuminated sCMOS platform on the market. The hermetically sealed vacuum enclosure also uniquely protects the sensor from attack by moisture and other gas contaminants, thus preserving both QE and cooling performance year after year.

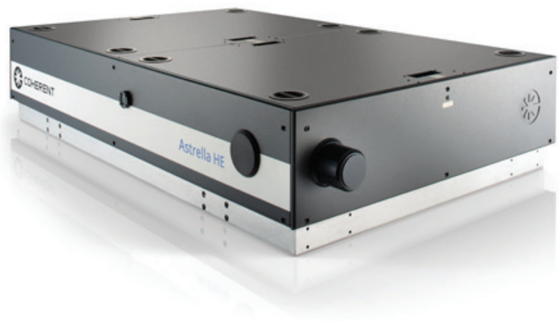
Coherent releases new high energy version of Astrella one-box amplifier

Coherent has expanded its successful Astrella amplifier platform by introducing the new Astrella HE. Delivering 9mJ at 1kHz, Astrella HE is the highest energy one-box kHz regenerative amplifier on the market. In addition to the improved energy at 1kHz, the Astrella HE is also available in a high power, higher repetition rate model, delivering 10W at 5kHz. Both version are available with a choice of pulsewidths – either 100fs or 35fs.

The integrated, one-box design employs the new STAR (STable ARchitecture) 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 improved overhead, stability and beam quality. The final key sub-system is the advanced, sealed stretcher/compressor designed for superb dispersion compensation and durability.

Researchers in Physics and Physical Chemistry, can use Astrella HE to pump tunable optical parametric amplifiers (OPA's) either to simultaneously run multiple experiments, or to run single experiments that need multiple independently tunable wavelengths.

Astrella HE also dramatically decreases the entry barrier to applications so far addressed by complex and more expensive, multi-box ultrafast amplifiers. Applications like EUV generation or laser plasma acceleration can now be addressed with a compact amplifier, resulting in a cost-effective, compact and reliable set up.



For further information please contact Dr Paul Wardill, sales@coherent.com.au

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

The Healing Power of Data: Florence Nightingale's True Legacy

by Alice Richardson, Jessica Kasza and Karen Lamb

This article was originally published on
THE CONVERSATION

When you're in a medical emergency, you don't typically think of calling a statistician. However, the COVID-19 outbreak has shown just how necessary a clear understanding of data and modelling is to help prevent the spread of disease.

One person understood this a long time ago. Were she alive today, Florence Nightingale would understand the importance of data in dealing with a public health emergency.

Nightingale is renowned for her career in nursing, but less well known for her pioneering work in medical statistics. But it was actually her statistical skills that led to Nightingale saving many more lives.

An early spark

Nightingale was one of the first female statisticians. She developed an early passion for statistics. As a child she collected shells and supplemented her collection with tables and lists. Nightingale was home-schooled by her father but insisted on learning maths from a mathematician before she trained as a nurse.

Upon arriving at the British military hospital in Turkey in 1856, Nightingale was horrified at the hospital's conditions and a lack of clear hospital records.

Even the number of deaths was not recorded accurately. She soon discovered three different death registers existed, each giving a completely different account of the deaths among the soldiers. Using her statistical skills, Nightingale set to work to introduce new guidelines on how to record sickness and mortality across military hospitals.

This helped her better understand both the numbers and causes of deaths. Now, worldwide, there are similar standards for recording diseases, such as the International Classification of Diseases.

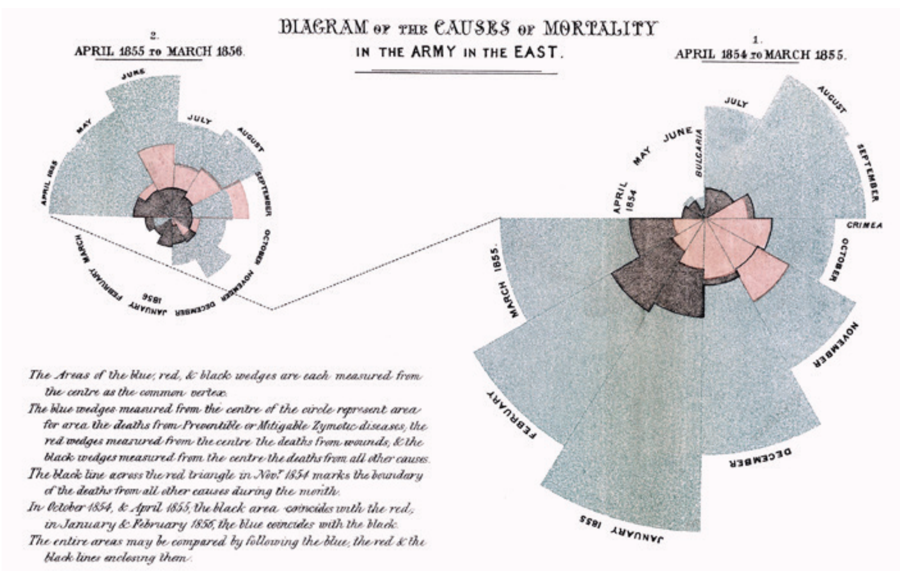
Outbreak monitoring

The ability to compare datasets from different places is critical to understanding outbreaks. One of the challenges in monitoring the COVID-19 pandemic has been the lack of standardised datasets experts can compare on the number of people infected. This is due to differences in testing rules in different countries.

More than 150 years after Nightingale pointed out the need to standardise datasets before comparing them, we are certain she would have something to say about this.

With her improved data, Nightingale put her statistical skills to use. She discovered deaths due to disease were more than seven times the number of deaths due to combat, because of unsanitary hospital conditions.

However, knowing numbers alone have limited persuasive powers, Nightingale used her skills in statistical communication to convince the British parliament of the need to act. She avoided the dry tables used by most statisticians of the time, and instead devised a novel graph to illustrate the impact of hospital and nursing practice reform on army mortality rates.



Florence Nightingale's graph showing deaths due to disease, wounds and other causes in the Crimean War. Wikimedia/commons.

A photo of Nightingale taken circa 1860. Wikimedia Commons.

Today, graphs remain one of the most effective ways to understand the effects of health care interventions, including those used to illustrate the effectiveness of physical distancing to curb COVID-19's spread.

Florence Nightingale down under

Nightingale may not have travelled much after her wartime experience in Turkey, but she was engaged in improving public health in many countries, including Australia.

She wrote papers on the benefits of pavilion-style hospital building designs, which were later incorporated into Australian hospitals. This style consists of small wings, or pavilions, leading off a central corridor – this is convenient for nursing staff and encourages good ventilation.

In 1868, Lucy Osburn headed the first team of nurses sent to Australia to establish Nightingale-style nursing. One of the team's first tasks was to nurse Prince Alfred, Queen Victoria's second son, who had been shot in an attempted assassination.

Nightingale never visited Australia herself, but this did not stop her using her usual tactics of requesting data from her wide network of contacts and drawing conclusions from what she found. She was a prolific correspondent – we have more than 12,000 of her letters, and those are only the ones which haven't been burned, lost or otherwise destroyed.

Nightingale would surely have embraced 21st-century communication. We can imagine her sitting at her laptop tweeting under the moniker @ladywiththelamp.

A trailblazer for women

In 1858, Nightingale's achievements in statistics were recognised by the Royal Statistical Society in the UK, when she became the first woman Fellow of the Society.

After Nightingale's fellowship, it would be more than 100 years before a woman was elected President of the Royal Statistical Society, with Stella Cunliffe's election in 1975. It was only in 1995 that the Statistical Society of Australia had a woman as president, with the election of Helen MacGillivray.

As in many STEM (Science, Technology, Engineering and Mathematics) disciplines, female statisticians are still fighting for equal recognition. To date, only two women have received the Statistical Society of Australia's highest honour, the Pitman Medal.

But it's clear female statisticians are still making headway. In 2019, five major statistical associations had women presidents. 200 years after her birth, Nightingale would have been proud.

Alice Richardson is Director of the Statistical Consulting Unit, Australian National University. Jessica Kasza is with the School of Public Health and Preventive Medicine, Monash University and is Vice-President of the Statistical Society of Australia. Karen Lamb is with the Centre for Epidemiology and Biostatistics, University of Melbourne.

Original article: https://theconversation.com/the-healing-power-of-data-florence-nightingales-true-legacy-134649

Presidents of Statistical Societies in 2019. L-R: Karen Kafadar (American Statistical Association), Louise Ryan (International Biometric Society), Deborah Ashby (Royal Statistical Society), Helen MacGillivray (International Statistical Institute), Susan Ellenberg, Jessica Utts (former President of the American Statistical Association), Susan Murphy (Institute of Mathematical Statistics). Image credit: ISI 2019 Kuala Lumpur.

PHOTON SCIENTIFIC

Melbourne, Australia

Bringing to you new innovative products & services

SPECTRAL PRODUCTS, USA

DK480: ½ M Monochromator, Wavelength Selection is No Longer Expensive

The Digikröm DK480 is a complete computer integrated solution. Easy to use commands control the triple grating turret, motorized slits, and optional motorized filter wheel for quick and easy sorting. Instrument mode can be set for constant spectral resolution (CSR), where the slit width is automatically modified to compensate the change in dispersion with wavelength to maintain constant spectral bandpass. Rugged cast construction, A-Thermal design, and SP direct grating drive make this unit the most repeatable and reliable in its class. Each instrument is calibrated and certified prior to delivery.

- ***Connects to any computer via RS 232 or IEEE-488***
- ***Triple-grating turret allows high efficiency scanning across a broad spectral range***
- ***May be factory configured as a monochromator or a spectrograph***
- ***Scans in both directions and with Constant Spectral Resolution (CSR)***
- ***Integrates with SP filter wheel for automatic filter switching***
- ***Suitable for fluorescence and absorption studies, detector characterization, thin film measurements, etc***

DK 480	Specifications		
Design	Czerny-Turner : standard Triple grating turrets	Focal length	480mm
Reciprocal Dispersion	1.60nm/mm (with 1200 g/mm grating)	f/#	7.8
Wavelength Precision	0.007nm (with 1200 g/mm grating)	Drive	Bidirectional
Wavelength Accuracy	± 0.30nm standard (with 1200 g/mm grating)	No backlash	Computer controlled
Scan Speed	1 to 1200nm/min (with 1200 g/mm grating)	Grating 1x3	68/68 or 68/84 mm
Stray Light	< 0.01% @220nm	Interface	RS232 Standard
Max. Resolution	0.06nm (with 1200 g/mm grating)	Software	Control, Labview drive
Slits	Width: 10µm - 3000µm, Height: 2mm - 20mm	Unilateral	Curved/straight

SM 200/SM400 MINIATURE OEMCCD SPECTROMETER

- Compact modular design for OEM Integration and Fully Customizable
- Direct light input to slits or via Fiber
- CCD allows wide spectral range 200-1050 nm
- Supports up to 8 USB multichannel configuration
- Enhanced dark current noise
- High Speed Data Acquisition

VISIT OUR WEBSITE

www.photonscientific.com.au

CONTACT US

email: photon@photonscientific.com.au

phone: +61 (0)3 85026393

Nonlinear Optics with Metasurfaces

by Thomas Pertsch and Yuri Kivshar

Nonlinear optics is a well-established discipline that traditionally relies on macroscopic media and employs propagation distances much longer than the wavelength of light. However, recent progress with electromagnetic metamaterials allows expanding this field into new dimensions to analyse novel phenomena and functionalities. Nonlinear effects in thin artificially structured *metasurfaces* do not rely on the phase-matching conditions and symmetry selection rules of natural materials, and nonlinear processes in metasurfaces may go beyond simple harmonic generation and spectral broadening, substantially expanding functionalities of optical metadevices. Here we provide a brief review of some recent topics and results on the physics of nonlinear optical metasurfaces.

Introduction

In recent years, metasurfaces have attracted a lot of attention in the optics community as highly functional, broadband, large-area structures and flat-optics components, which are rapidly advancing towards real applications. While the study of the linear properties of metasurfaces is already entering the engineering field, applications of *nonlinear metasurfaces* are only just emerging. Detection and generation of light with new frequencies, as well as generation and control of single photons for quantum information applications are significant for a range of modern technologies and drive the research of nonlinear optical metasurfaces to increase their performance and functionality. The nonlinear processes are empowered by the existence of electric and magnetic Mie resonances and their nonlinear material interactions, such as switching the phase of the fundamental and harmonic fields due to the nonlinear response of the component materials and a precise control of structural dimensions at the nanoscale.

Here, we concentrate on the most recent achievements in the field, which have been enabled by multiple advances to control light with nanostructured dielectric metasurfaces made from resonant structures and strongly nonlinear materials, such as semiconductors. In contrast to the long established research field of metal-based plasmonic metasurfaces, their low-loss twin, all-dielectric metasurfaces has just emerged over the past few years. However, dielectric nanostructures in a multitude of high-index materials have already outperformed established metals in many applications, due to their considerably lower intrinsic losses.

Recently, the research focus of dielectric resonant metasurfaces has broadened to study active [1] and nonlinear [2] structured surfaces, where in addition to the low loss, the increased field overlap of the excited Mie-like resonances with the nonlinear dielectric resonances and the higher damage threshold become equally important. Being driven by important novel functionalities of nonlinear metasurfaces, we discuss here some recent achievements in realising frequency conversion and high-harmonic generation, and also review some recent demonstrations of nonlinear metadevices based on nonlinear interactions and frequency conversion.

Resonances in metasurfaces

Resonances play a crucial role in the physics of metasurfaces because they allow substantial enhancement of both the electric and magnetic fields important for nonlinear nanophotonics. We can identify several physical mechanisms for field enhancement and mode engineering in metasurfaces. This includes *local resonances*, such as surface plasmon resonances and Mie resonances of individual metallic and dielectric nanoparticles, and also *collective resonances* such as guided-mode resonances, Fano resonances, and bound states in the continuum.

Mie resonances are traditionally associated with the exact Mie solutions of Maxwell's equations for isolated spherical particles. In a broader context, they can be employed for the control of light below the free-space diffraction limit by high-index dielectric nanoparticles, and recently they attracted a lot of attention because they can support both electric and magnetic modes of comparable strengths [3].

Periodic media exhibit numerous interesting properties, also supporting both leaky and non-leaky modes for each supported resonant Bloch wave if the lattice is symmetric. The non-leaky mode is associated with a *bound state in the continuum* (BIC), or an embedded eigenvalue, which are currently of considerable scientific interest [4]. A true BIC is a mathematical object with an infinite quality factor (Q factor) and vanishing resonance width. In practice, BIC can be realised as *quasi-BIC modes* when both the Q factor and resonance width become finite. Recently, it has been shown that the resonant response of dielectric metasurfaces composed of meta-atoms with broken in-plane inversion symmetry can support high-Q resonances directly associated with the concept of BIC [5]. All such structures can be employed in nonlinear nanophotonics, since they give rise to strong light-matter interaction at the nanoscale. We notice here that there exists a direct link between quasi-BIC states and Fano resonances since these two phenomena are supported by similar physics [4, 5].

Figure 1 shows several examples of dielectric metasurfaces supporting quasi-BIC resonances shown as SEM images of the fabricated planar structures. The example in figure 1(a) shows a section of the silicon metasurface with the highest value Q factor demonstrated so far [6] exceeding Q=18,000. Figure 1(b) shows a Ge-based high-Q metasurface capable of delivering a multitude of spectrally selective and surface-sensitive resonances between 1100 cm^{-1} and 1800 cm^{-1} for detecting distinct absorption signatures

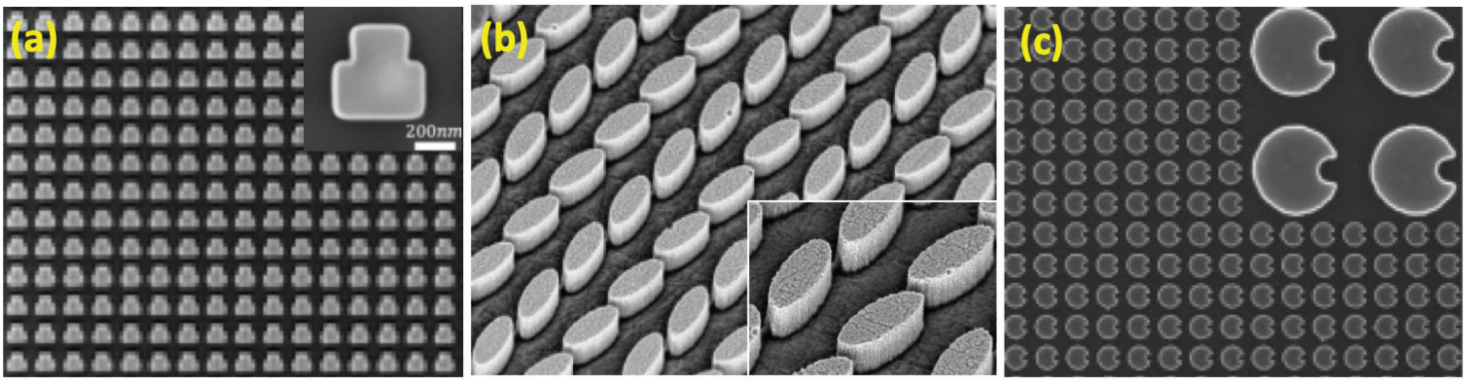


Figure 1. Examples of resonant dielectric metasurfaces. Periodic lattices with a broken in-plane symmetry supporting quasi-BIC resonances, shown as SEM images of the fabricated planar structures. (a) Silicon metasurface demonstrating the highest values of the Q factor [6], (b) the structure of one pixel of the pixelated germanium metasurface employed for biosensing [7], and (c) silicon metasurface composed of nanodisks with notches for enhancing light-matter interaction [8].

of different interacting analytes including proteins, aptamers, and polylysine [7]. Finally, the example in figure 1(c) shows a light-emitting quasi-BIC-based metasurface that combines an asymmetric Si nanorod array with embedded Ge quantum dots. For the latter metasurface, the authors observed light emission intensity enhancement and specific polarisation of far-field radiation driven by the symmetry-breaking induced Fano resonances associated with quasi-BIC modes [8].

Frequency conversion in nonlinear metasurfaces

Naturally, resonant excitations in metasurfaces boost light-matter interactions. Due to the resonant field enhancement inside dielectric nanostructures, nonlinear light-matter interactions can occur already for easily accessible excitation intensities. However, besides the onset of nonlinear effects for reduced excitation powers and the increased damage threshold as compared to metal nanostructures, dielectric metasurfaces offer multiple additional advantages for the generation, control, and exploitation of nonlinear optical effects. These advantages, in analogy to the field enhancement, derive from the resonant excitations in the thin nanostructured films of dielectric nanoresonators. The following specific properties seem to be important:

(A) *Phase matching*: The thin-film nature of metasurfaces, with thicknesses smaller than the wavelength of light, practically resolves any phase-matching issue, which otherwise often hampers nonlinear effects in macroscopic waveguide devices or bulk crystals. The reduced nonlinear efficiency, which is a consequence of the strongly decreased interaction length in thin metasurfaces, can be at least partially compensated by resonant field enhancement.

(B) *Field overlap*: Since electromagnetic fields can penetrate into dielectric materials, there is a strong overlap of the resonantly excited modes with the nonlinear material of the dielectric nanostructures composing the metasurfaces. In contrast to plasmonic nanostructures, where the field is enhanced mainly at the surfaces of the nanostructures, this improved overlap gives rise to the high nonlinear interaction efficiencies of dielectric metasurfaces. In more detail, this overlap is often strongest for higher-order resonances, e.g. *magnetic dipole resonances*.

(C) *Symmetry breaking*: While many nonlinear interactions, which are present on the microscopic level, do not result in macroscopic effects due to their suppression by symmetries of the materials and/or fields, nanostructured dielectrics can break the symmetry of both the materials on a nanoscopic level and the fields. Trivially, the surface to volume ratio is enhanced for nanostructures, strengthening nonlinear surface effects. This can be enhanced further by breaking the nanostructures' symmetries on nanoscopic scales. Moreover, compared to the quite trivial vectorial orientations of electromagnetic fields in bulk media, the hybridisation of fields for higher-order modes in high-index dielectric nanostructures can be the origin of nonlinear interactions, which are symmetry-forbidden in bulk media.

(D) *Dispersion*: Resonant interactions, as they occur in dielectric metasurfaces, are inherently dispersive in that they are showing different behaviour for different excitation frequencies. While this is often considered a problem which obstructs broad-band operation or induces phase-mismatch in nonlinear frequency generation, we assume the perspective that this is a versatile feature, which should be exploited to tailor nonlinear interactions. Thus by providing an almost arbitrary control over the frequency dependence of the density of states in resonant dielectric metasurfaces, higher-order nonlinear frequency generations can be tailored at will or short pulses can be nonlinearly reshaped, just by controlling the linear dispersion properties of metasurfaces.

(E) *Spatial mode tailoring*: Since the resonant properties of the nanostructured metasurfaces depend strongly on the geometry of nanostructures, the resonances can be spatially changed by varying the nanoscale geometries across the metasurfaces. While the nonlinear properties of bulk are spatially homogeneous, this tailorability of the nanostructures allows tuning the linear and nonlinear properties across the metasurfaces, the interplay of which can be exploited for complex spatiotemporal nonlinear beam shaping and control.

<u>Second-harmonic generation</u> (SHG), the creation of one high-energy photon (at the so-called second-harmonic frequency) from two low-energy photons (at the so-called fundamental harmonic frequency) of a single excitation beam, is a second-order nonlinear optical process. On the molecular level, it is therefore the strongest nonlinear process when compared to higher-order nonlinearities. Already quite early in the development of plasmonic metasurfaces, SHG was investigated in non-centrosymmetric metal nanostructures. However, these

plasmonic implementations of nonlinear metasurfaces suffered from the intrinsic losses of metals and from the relatively low damage thresholds induced by these losses due to heating of the nanostructures. The latter fact limits nonlinear applications of metasurfaces due to the power dependence of the SHG efficiencies.

Realisations of efficient dielectric nonlinear metasurfaces with densely-arranged nanoparticles concentrated on III-V semiconductors with high second-order nonlinearities, GaAs and AlGaAs. In the metasurfaces, the SHG efficiency was increased as compared to homogeneous films, initially by exploiting magnetic dipole resonances in symmetric nanoresonators (see figures 2(a-c) and reference [9]) but later even higher efficiencies could be obtained with Fano resonances and quasi-BIC modes in broken-symmetry metasurfaces.

Third-harmonic generation (THG), the creation of one high-energy photon (at the so-called third-harmonic frequency) from three low-energy fundamental-frequency photons of a single excitation beam, is a third-order nonlinear optical process. On the molecular level, it is therefore weaker than the second-order nonlinearity, which was discussed above. However, unlike second-order nonlinear effects, third-order effects do not require non-centrosymmetry and hence are observed for all materials on a macroscopic scale. Therefore, the vastly available Si and to a lesser extent also Ge became the materials of choice for the realisation of THG in metasurfaces. While argument C from above does not have to be considered for nonlinear properties, all other arguments remain equally important for THG. Due to a large frequency shift from the fundamental harmonic to the third-harmonic, dispersion in resonant metasurfaces becomes even more important for THG than for SHG.

Due to the maturity of silicon nanofabrication, the understanding of THG in isolated silicon nanoantennas has been translated rapidly to large-scale metasurfaces [10, 11]. Also, based on the high precision of Si nanofabrication, complicated geometries could be realised, which besides the well-established Mie resonances of the individual nanoresonators, give rise to collective resonance effects, like Fano resonances and quasi-BIC modes, see figures 2(d, e).

High-harmonic generation and frequency mixing

High-harmonic generation (HHG) was first reported for gases, being considered as one of the fundamental processes in strong-field physics and attosecond photonics. Recently discovered HHG in solids [12] provides a new way to investigate novel photonic applications that cannot be realised in gases. In particular, it opens the possibility of generating and controlling the high harmonics directly from subwavelength nanostructures. The effect of nanostructures on solid-state HHG is twofold: first, each individual nanoscale feature interacts with and scatters fundamental light in a non-trivial way depending on its geometry; second, HHG emission profiles in the far field can be controlled by arranging the location of individual nanostructures.

All-dielectric resonant nonlinear metasurfaces provide an attractive platform to control HHG and other

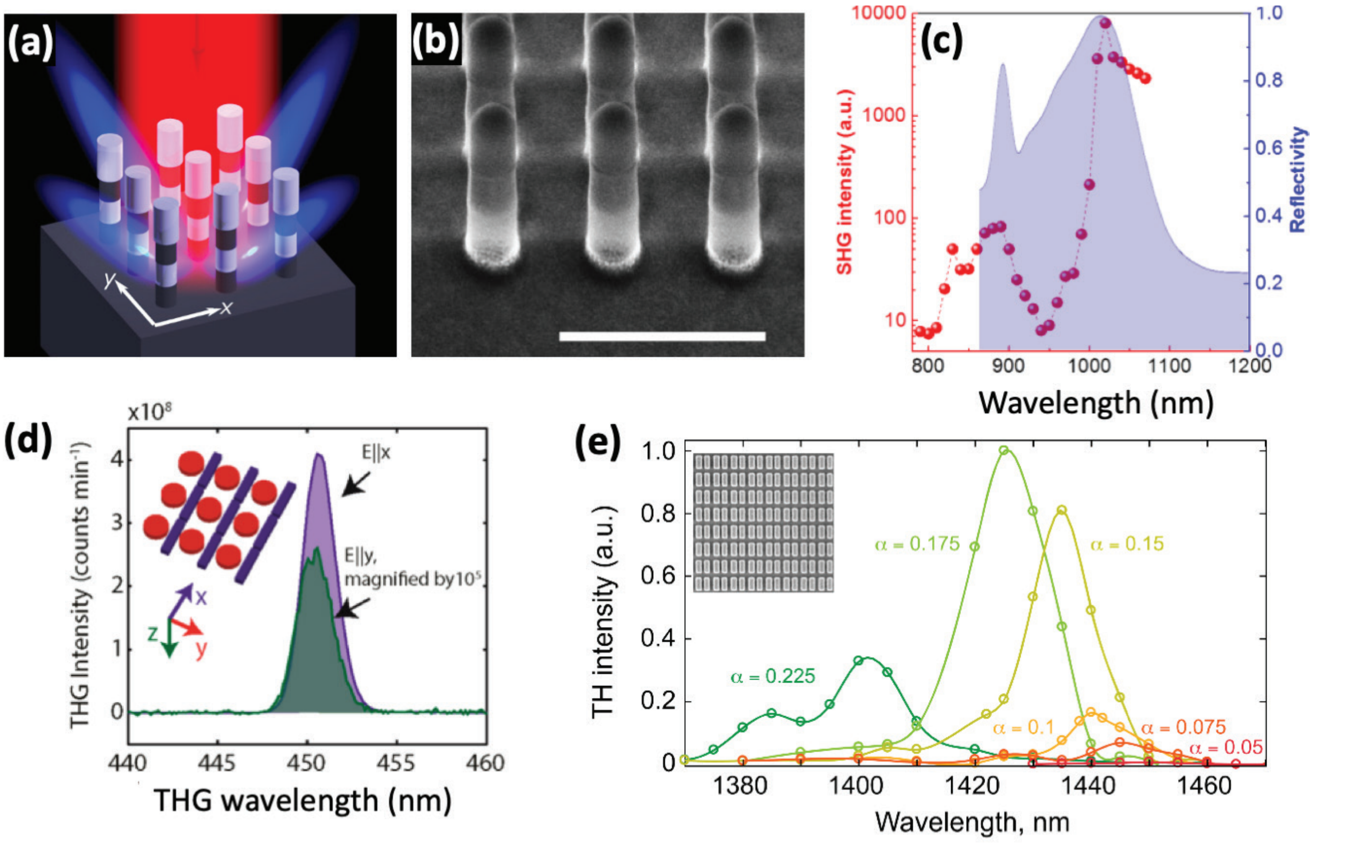


Figure 2. Enhanced second- and third-harmonic generation with metasurfaces. (a-c) SHG from semiconductor metasurfaces. Magnetic dipole resonances in a GaAs metasurface (illustrated by its SEM image) lead to strong SHG from bulk and surface nonlinearities observed in (c) with 10^4 enhancement with respect to an unpatterned GaAs film [9]. (d, e) THG in silicon metasurfaces with different nanoscale geometries for exploiting specific resonance schemes. (d) Utilising a Fano-resonant silicon metasurface and strong near-field enhancement result in polarisation-dependent THG with 1.5×10^5 enhancement compared to an unpatterned Si film [10]. (e) Quasi-BIC for THG enhancement depending on the parameter α characterising the geometrical asymmetry of the Si double-bar lattice [11].

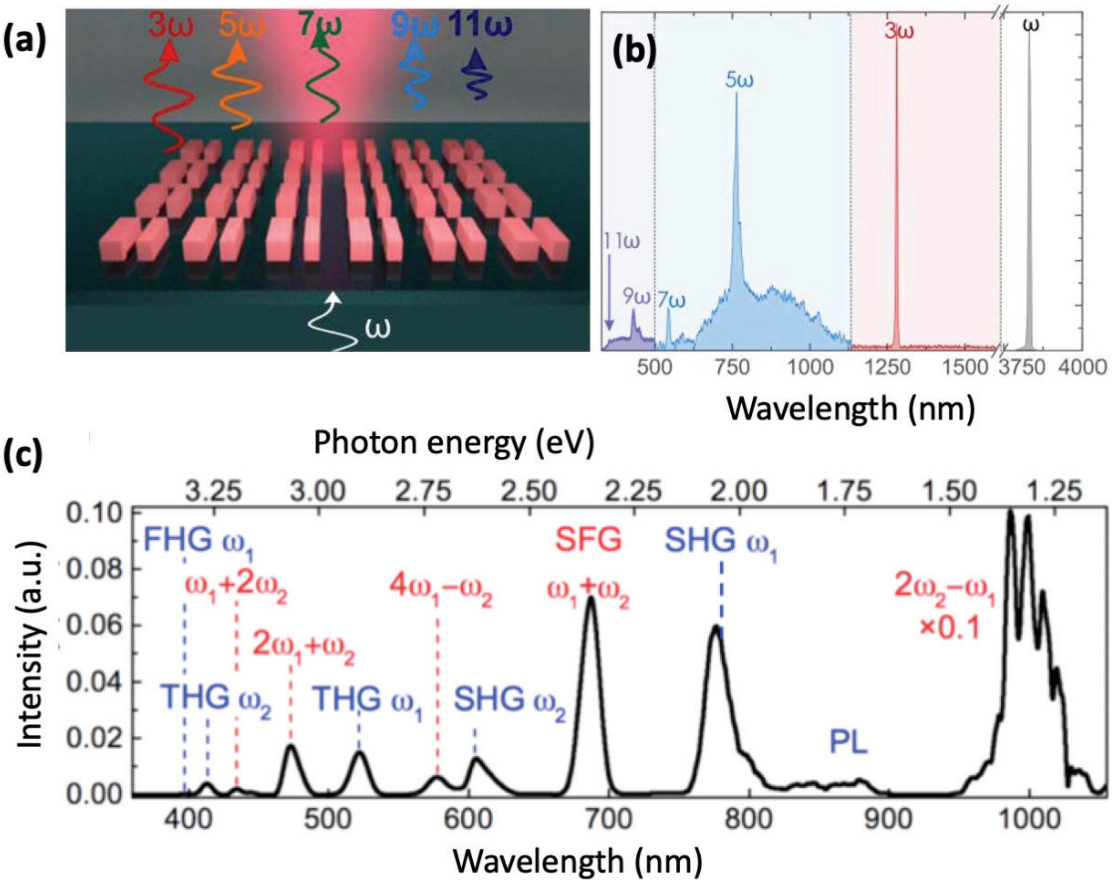


Figure 3. High-harmonic generation with metasurfaces. (a, b) Observation of 3rd to 11th optical harmonics in nonlinear silicon metasurfaces, shown with a concept image and combined spectral measurements of the generated signals. The blue spectral region is obtained with Si spectrometer QE Pro, the red spectral region is measured with InGaAs spectrometer NIR Quest, the grey region shows the pump spectrum. The broad spectral signal in the vicinity of the 5th harmonic is associated with multi-photon luminescence of Si [13]. (c) Spectrum of the frequency mixing exhibiting eleven peaks originating from seven different nonlinear processes when two optical beams at $\lambda_2 \sim 1.24$ µm and $\lambda_1 \sim 1.57$ µm are used to simultaneously pump GaAs metasurface. Blue labels: harmonic generation and photoluminescence arising from two-photon absorption with one pump beam. Red labels: frequency mixing that involves both pump beams [14].

high-field processes at the nanoscale. As discussed above, by using collective resonances in metasurfaces, one may enhance the harmonic emission by several orders of magnitude compared to unpatterned samples. Recently, Zograf et al [13] observed a dramatic enhancement of the efficiency of HHG in dielectric metasurfaces hosting quasi-BIC modes. A dielectric metasurface is composed of complex meta-atoms in the form of an asymmetric pair of dielectric rectangular bars, as shown in figure 3(a).

Zograf et al [13] pumped the BIC metasurface with a pulsed mid-infrared laser system consisting of an fs laser Ekspla Femptolux, and an optical parametric amplifier MIROPA Hotlight Systems. To detect the signal, they used a pair of peltier-cooled spectrometers working in the visible-to-near-infrared range (QE Pro by Ocean Optics) and near-infrared range (NIR-Quest by Ocean Optics). When the metasurface is pumped at 3830 nm wavelength with 2 ps pulses at 5MHz repetition rate, it produces the signal spectrum shown in figure 3(b). The spectrum features the maxima corresponding to the generation of 3rd, 5th and 7th harmonics. They next shorten the pulse duration to 80 fs and repetition rate to 1 kHz with optical parametric amplifier TOPAS pumped by the femtosecond laser system Coherent Astrella. With this, Zograf et al [13] observed 9th and 11th optical harmonics, shown in the purple region in figure 3(b).

Metasurfaces made from III-V semiconductors have been employed to show frequency mixing, including generation of the second-, third- and forth-harmonic, as well as four-wave mixing and six-wave mixing nonlinear processes [14]. Such metasurfaces consist of periodic arrays of cylindrical resonators with three layers: the top is an SiOx etch mask that is an exposed HSQ photoresist; the middle is the GaAs layer, and the bottom layer is the oxide $(Al_{0.85}Ga_{0.15})_2O_3$. When the two femtosecond pump beams simultaneously pump the GaAs metasurface with wavelengths overlapping with the magnetic and electric dipolar resonances, the nonlinear generation of eleven new frequencies with spectra spanning from UV to near-IR can be detected, see figure 3(c). Due to the small feature size of the resonators, the metasurface relaxes phase matching conditions, and it leads to the possibility of the generation of a few different nonlinear processes at the same time. The newly generated frequencies can be divided into two groups, see figure 3(c). The first group relies only on one beam: SHG, THG, fourth harmonic generation (FGH) and photoluminescence (PL). The second group of signals relies on two pump beams: sum-frequency mixing (SFG), six-wave mixing (SWM), and three peaks that correspond to four-wave mixing (FWM) processes.

Nonlinear metadevices

Metasurfaces emerged as a two-dimensional version of metamaterials with the properties going beyond those described by effective or averaged parameters. Being structured on the subwavelength scale, metasurfaces extended substantially the concept of diffraction gratings and they became a paradigm for engineering electromagnetic space and controlling propagation of waves. The current research agenda is to achieve tunable, switchable, nonlinear and sensing functionalities of metasurfaces, thus creating a platform for the emerging field of planar metadevices, which we define as devices with unique and useful functionalities realised by the structuring of functional matter on the subwavelength scale. In this section we discuss several experimentally demonstrated *nonlinear metadevices* engaging the nonlinear response of their subwavelength components.

Wang et al. [15] suggested a general approach for engineering the wavefront of parametric waves of arbitrary complexity generated by a nonlinear metasurface. They designed all-dielectric nonlinear metasurfaces with a highly efficient wavefront control of the third-harmonic field, and demonstrated the generation of nonlinear beams at a designed angle and the generation of nonlinear focusing vortex beams, as shown in figures 4(a, b). Their nonlinear metasurfaces produced phase gradients over a full 0–2π phase range. Figure 4(a, top) shows a directionality diagram (back-focal plane image) of the forward third-harmonic field. A total of 92 % of the third-harmonic field is directed into the designed angle θ = 5.6°.

The idea to employ nonlinear metasurfaces for sensing has been suggested for plasmonic metasurfaces [16]. A refractive index difference Δn in the environment of the metasurface causes a shift of its resonance frequency. In nonlinear sensing, the resonance is driven at frequency ω and the resonantly enhanced third harmonic at frequency 3ω serves as the sensor signal, as shown in figure 4(c). Because of the nonlinear conversion process, one can observe a larger sensitivity to a local change in the refractive index as compared to the commonly used linear localised surface plasmon resonance sensing [16]. Furthermore, simultaneous detection of linear and nonlinear signals allows comparison of both methods, providing further insight into the working principle of this sensor. While the signal-to-noise ratio is comparable, nonlinear sensing gives about seven times higher relative signal changes.

Nonlinear holographic metasurfaces have been intensively studied due to their potential in practical applications. Gao et al [17] demonstrated experimentally a novel mechanism for nonlinear holographic metasurfaces. In contrast to conventional studies, their all-dielectric metasurface is composed of C-shaped Si nanoantennas. The incident laser is enhanced by their fundamental resonance, whereas the generated third-harmonic generation signals are redistributed to the air gap region via the higher-order resonance, significantly reducing the absorption loss at short wavelength and resulting in an enhancement factor as high as 230. After introducing abrupt phase changes from 0 to 2π to the C elements, high-efficiency THG holograms have been experimentally generated with the Si metasurface, as shown in figure 4(d).

Another attractive application of metasurfaces is imaging by planar metalenses, which enables device miniaturisation and aberration correction compared to conventional optical microlens systems. An abrupt phase change of light at metasurfaces provides high flexibility in wave manipulation without the need of accumulation of propagating phase through dispersive materials [18]. With nonlinear responses, optical functionalities of metalenses are anticipated to be further enriched, leading to completely new application areas. Schlickriede et al. [18] have demonstrated an ultrathin *nonlinear metalens* using SHG from gold meta-atoms with three-fold rotational symmetry. The desired phase profile for the metalens was obtained by a nonlinear Pancharatnam–Berry phase that is governed by the meta-atom orientation angle and the spin state of the fundamental wave. For a near-infrared Gaussian laser beam, the authors experimentally realised the spin-dependent focusing effect of SHG waves at both real and virtual focal

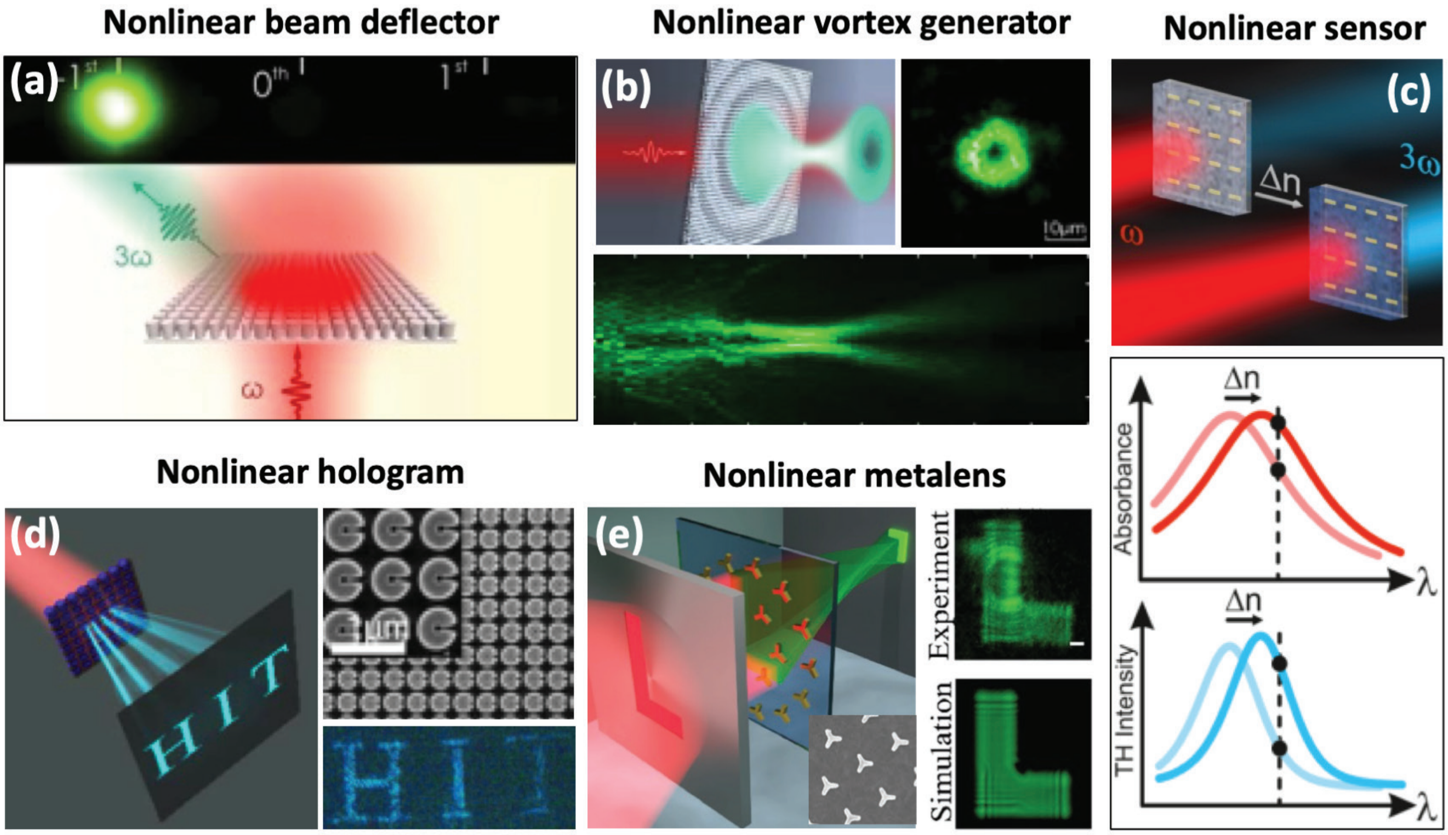


Figure 4. Examples of nonlinear metadevices. (a) Nonlinear beam deflector [15]. Top: Directionality diagram (back-focal plane image) of the forward third-harmonic field. (b) Nonlinear vortex beam generator [15]. Cross-sections of a generated donut-shaped vortex beam taken perpendicular to the optical axis and along the optical axis of the beam. (c) Principle of linear and nonlinear metasurface-based sensing [16]. (d) Nonlinear metasurface hologram. Insert shows an SEM image of the C-shaped Si metasurface [17]. (e) Schematic concept of nonlinear metalenses, with L-shaped apertures imaged on a screen with the help of the nonlinear metalens consisting of triangular nanoantennas [18] (see also [19])..

planes. Furthermore, they showed that objects, which are illuminated by near infrared light, can be imaged at visible wavelength based on the SHG process at the metalens, as shown in figure 4(e). The concept of a nonlinear metalens not only inspires new imaging technologies, but also it provides a novel platform for generating and modulating nonlinear optical waves.

Summary

For efficient nonlinear processes in optics, the engineering of the nonlinear properties of media becomes an important task. The well-known approach for engineering nonlinear optical properties is the quasi-phase matching scheme for enhancing second-order processes such as second-harmonic generation, based on binary periodic polling of natural crystals, which is equivalent to a discrete phase change of the nonlinear polarisation. The continuous control of the phase of the nonlinear susceptibility can greatly enhance flexibility in the design, the latter becomes possible with metamaterials. Thus, nonlinear metamaterials have fundamental significance in nonlinear optics for tailored nonlinearities, as they provide novel degrees of freedom in the design of optical materials with a nontrivial nonlinear response.

Metasurfaces, being assembled of two-dimensional arrays of optical resonators, do not require any phase-matching condition and they rely on local enhancement of both electric and magnetic fields, so resonances play an important role in the physics of nonlinear metasurfaces. We have outlined above some recent advances in the emerging field of nonlinear metasurfaces largely driven by dielectric nanostructures supporting local Mie-type and collective guided-mode resonances. This is a rapidly developing field with a great potential for applications in new types of beam control devices, frequency conversion with flat optics, next-generation displays, and quantum processing. A subwavelength confinement of the local electromagnetic fields in resonant high-index dielectric photonic nanostructures due to individual Mie and collective Fano resonances, as well as the interference physics of the different types of bound states in the continuum can boost many effects in nonlinear optics, thus offering novel opportunities for the subwavelength control of light at the nanoscale for components of future nonlinear metadevices. An open challenge in this respect is set by the limited product of Q factor and bandwidth, which is restricting the utilisation of ultrashort pulses for exciting the nonlinear response of metasurfaces with ultrahigh Q factors, due to the finite bandwidth of the resonant enhancement. However, strong non-perturbative nonlinear effects might introduce new solution strategies in this direction. Nonlinear metasurfaces highlight the importance of the optically-induced magnetic response in engineering nonmagnetic resonant structures for many applications in optics. These include optical sensing, parametric amplification, ultrafast spatial modulation of light, and nonlinear active media, as well as both integrated classical and quantum circuitry and topological photonics, underpinning a new generation of highly efficient flat-optics nonlinear metadevices.

Acknowledgements

The authors acknowledge useful input and discussions with their numerous colleagues and students at their research teams in Jena (Germany) and Canberra (Australia), and also productive collaborations with research groups from USA, China, and Russia.

References

[1] I Staude, T Pertsch, and YS Kivshar, ACS Photonics **6**, 802-814 (2019).
[2] Y Kivshar, National Science Review **5**, 144–158 (2018).
[3] S Kruk and YS Kivshar, ACS Photonics **4**, 2638-2649 (2017).
[4] K Koshelev, A Bogdanov, and Y Kivshar, Optics & Photonics News **31**, 38-45 (2020)
[5] K Koshelev, S Lepeshov, M Liu, A Bogdanov, and YS Kivshar, Phys. Rev. Lett. **121**, 193903 (2018).
[6] Z Liu, Y Xu, Y Lin, J Xiang, T Feng, Q Cao, J Li, S Lan, and J Liu, Phys. Rev. Lett. **123**, 253901 (2019).
[7] A Leitis, A Tittl, M Liu, BH Lee, MB Gu, YS Kivshar, and H Altug, Science Advances **5**, eaaw2871 (2019).
[8] C Cui, S Yuan, C Zeng, and J Xia, In: IEEE 16th International Conference on Group IV Photonics (GFP), 1949-209X (2019); doi: 10.1109/GROUP4.2019.8853898.
[9] S Liu, MB Sinclair, S Saravi, GA Keeler, Y Yang, J Reno, GM Peake, F Setzpfandt, I Staude, T Pertsch, and I Brener, Nano Lett. **16**, 5426 -5432 (2016).
[10] Y Yang, W Wang, A Boulesbaa, II Kravchenko, DP Briggs, A Puretzky, D Geohegan, and J Valentine, Nano Lett. **15**, 7388-7393 (2015).
[11] K Koshelev, Y Tang, K Li, D-Y Choi, G Li, and Y Kivshar, ACS Photonics **6**, 1639 -1644 (2019).
[12] G Ndabashimiye, S Ghimire, M Wu, DA Browne, KJ Schafer, MB Gaarde, and DA Reis, Nature **534**, 520-523 (2016).
[13] G Zograf, A Zalogina, K Koshelev, DY Choi, V Korolev, R Hollinger, D Kartashov, M Zürch, C Spielmann, S Makarov, B Luther-Davies, S Kruk, and Y Kivshar, CLEO FTh1C.5 (2020).
[14] S Liu, PP Vabishchevich, A Vaskin, JL Reno, GA Keeler, MB Sinclair, I Staude, and I Brener, Nature Communications **9**, 2507 (2018).
[15] L Wang, S Kruk, K Koshelev, I Kravchenko, B Luther-Davies, and Y Kivshar, Nano Lett. **18**, 3978- 3984 (2018).
[16] M Mesch, B Metzger, M Hentschel, and H Giessen, Nano Lett. **16**, 3155-3159 (2016).
[17] Y Gao, Y Fan, Y Wang, W Yang, Q Song, and S Xiao, Nano Lett. **18**, 12, 8054-8061 (2018).
[18] C Schlickriede, N Waterman, B Reineke, P Georgi, G Li, S Zhang, and T Zentgraf, Adv. Mat. **30**, 1703843 (2018).
[19] C Schlickriede, S Kruk, L Wang, B Sain, Y Kivshar, and T Zentgraf, Nano Lett. **20**, 4370-4376 (2020).

Professor Thomas Pertsch is with Friedrich Schiller University Jena, Germany. His research interests include nano and quantum optics, metamaterials, and nanophotonics. He is a member of the Abbe Center of Photonic (Jena, Germany) as well as Fellow of the OSA and of the Max Planck School of Photonics.

Professor Yuri Kivshar is with the Nonlinear Physics Centre, Australian National University, Australia. His research interests include nonlinear physics, metamaterials, and nanophotonics. He is a Fellow of the Australian Academy of Science, and also a Fellow of OSA, APS, SPIE, and IOP.

gentec-eo

LASER POWER & ENERGY METERS

Complete range of laser measurement products, with energy detectors from nJ to several kJ and power detectors from a few pW to tens of kW.

BEAM PROFILING

Full range of beam profilers, including cameras and scanning systems to measure beam diameter, intensity profile, divergence and even M².

CUSTOMISATION & OEM

With more than 40 years experience, Gentec-EO have developed numerous customised solutions. Contact us with your requirements today.

TRACEABLE CALIBRATION

Gentec-EO use only Gold Calibrations standards, guaranteeing our customers the best accuracy on the market. We also offer our in-house calibration expertise to customers outside the laser market so do not hesitate to bring us all your calibration needs.

NIST
Traceable

Ocean Insight

Previously known as Ocean Optics, Ocean Insight is evolving from the world's leader in miniature spectroscopy devices to a singular provider of Applied Spectral Knowledge. "Insight" reflects the knowledge we bring, the solutions we provide, and the partnerships we value.

OCEAN MZ5

The MZ5 spectrometer for MIR analysis is fully self-contained and can be custom engineered for more complex projects.

PERFORMANCE

- Spectral range: 1818–909 cm-1 (5.5-11 µm)
- Signal to noise: >300:1 or better (60 s measurement)
- Spectral bandwidth (FWHM): 75 cm-1 (at CWL)
- Measurement time (typical): ~30 seconds (N=200)
- Measurement time (typical): ~30 seconds (N=200)
- Storage environment: 0-60 °C non-condensing

sales@lastek.com.au | www.lastek.com.au

Lastek
Photonics Technology Solutions

More than 10,000 Job Losses, Billions in Lost Revenue: Coronavirus will Hit Australia's Research Capacity Harder than the GFC

by Frank Larkins and Kylie Walker

This article was originally published on THE CONVERSATION

Australia's researchers have answered the call to help with urgent pandemic clinical trials and other research needs, placing other work on hold. Experts across a broad range of disciplines are crucial to our health, mental health and economic well-being. And yet the COVID-19 pandemic has posed one of the most significant threats in history to Australia's national research sector, and well beyond the medical sciences.

We were lead authors on a report for the government's National COVID Coordination Commission through the Chief Scientist's Rapid Research Information Forum (RRIF). We answered the question:

What impact is the pandemic having and likely to have on Australia's research workforce and its capability to support our recovery efforts?

Our report shows Australia's research workforce will be severely impacted by the pandemic, with the effects likely to be felt for years, if not decades.

The universities sector estimates its revenue will drop by at least A$3 billion in 2020 due to the pandemic, and the decline could be as high as A$4.6 billion. This drop is likely to be worst for research-intensive universities.

Early and mid career researchers and recent graduates will be disproportionately affected due to the highly casualised and fixed-term nature of the university research workforce. This may also be the case for women, who more commonly than men have additional childcare and other home commitments.

Journals are already seeing that since the COVID-19 crisis began, submissions from women are underrepresented, especially articles authored solely by women.

Australia's research spending

We canvassed and compiled evidence from across Australia's universities, publicly and privately funded research institutes and agencies, and the private sector.

The Australian government provides support for the research workforce through grant funding and tax transfers to industry, paying the salaries of researchers in government agencies and departments, and providing grant funding through research councils and block funding to universities.

In 2019–20 this was budgeted to be a total of A$9.6 billion. Of this

- A$2.1 billion went to industry
- A$2.1 billion went to government research activities (including CSIRO, the Australian Institute of Medical Scientists, the Australian Nuclear Science and Technology Organisation and Defence)
- A$3.6 billion went to universities
- A$1.8 billion went to medical research institutes and other sectors like agriculture and energy.

Australian spending on research (from all sources, including government and industry) has flatlined over the last few years, and declined overall.

Investment increased from A$6,667 million in 2007-08 to A$10,072 in 2011-12. But it steadily declined from its peak of A$10,072 million 2011-12 to a low of A$9,396 million in 2018-19 (apart from a one-off A$10,285 million spike in 2017-18).

Government funding is steady at its budgeted A$9.6 billion this financial year. But given business spending on research and development dropped 3.1% during the global financial crisis, it is expected to drop precipitously due to the pandemic.

In Australia, industry is responsible for 86% of experimental development (where physical experiments are used to test a hypothesis). And small to medium enterprises (which comprise the vast majority of Australian businesses) are unlikely to have spare cash to invest in research and development.

Universities perform around 43% of all applied research (aimed at solving real-world problems) in Australia. This means industry sectors relying on universities and research institutions for research and development may be less able to collaborate, innovate and create new sources of employment.

Almost half of Australia's 164,000 researchers are academic staff and postgraduate research students. Universities expect to lose up to 21,000 full-time equivalent staff over the next six months, of which an estimated 7,000 could be research-related.

Postgraduate research students work in research while earning their higher degree. They're 57% of the university workforce and 6,000 could lose their jobs.

In medical research institutes, around 3,000 jobs are projected to go. There is widespread concern the diversity crucial to innovation will be lost along with these jobs.

much of Australia's medical research including in cancer, heart disease, motor neurone disease and diabetes.

This will seriously impact Australia's capacity to pick up when it is safe to re-open these laboratories

During the global financial crisis, the government recognised the threat to research and its capacity to pull Australia through. It injected an additional $1 billion in funding into academic research between 2008-09 and 2013-14.

During the COVID-19 pandemic, the Australian government has invested about an extra A$13 million into the Medical Research Future Fund to support COVID-related research.

The UK government has recognised the need to support research-led economic recovery. As well as establishing a research sustainability taskforce, it's just announced it will bring forward £100 million of quality-related research funding for providers into this current academic year as immediate help to ensure Britain's research activities can continue during the crisis.

The funding is paired with guarantees to protect tertiary student places and PhD student grants.

The Australian government also has the opportunity to show visionary leadership by investing to support the broader research and development that will be vital to the nation's economic recovery.

International student revenue

The university sector supplements government research funding with income from full-fee paying international students. This represents an average 26% of individual universities' total revenue.

Around A$4.7 billion is spent on research from university discretionary funds, the majority of which comes from international student fees (although it also includes donations and investment returns).

In 2018, 37% of PhD students in Australia were international students. And 75% of those were performing research in science, technology and engineering subjects.

Many international postgraduate students have limited options to extend their stay to make up for research interruptions. Some have already returned to their country of origin.

These factors, together with likely future travel restrictions, mean we can anticipate more than 9,000 international research students may not be able to resume their research programs in 2020.

Australia's university research capacity has arguably taken a bigger blow than any other country because of our higher proportion of overseas students.

The overall loss of research capacity doesn't just affect the creation of new knowledge. It will significantly affect Australia's future potential for economic growth.

An opportunity for Australia

Corporate-sponsored research enables Australian industries – such as health, advanced manufacturing, transport and renewable energies – to be competitive. This subsequently creates new employment opportunities and supports economic growth.

Labs in medical research institutes not working on COVID-19 research have been closed. They have effectively paused

The report this article is based on was produced by the The Rapid Research Information Forum, a group of 35 research sector organisations and science leaders. The forum is chaired by Australia's Chief Scientist, Dr Alan Finkel, and its operations are led by the Australian Academy of Science.

Frank Larkins is a Professor Emeritus and Former Deputy Vice Chancellor, University of Melbourne. Kylie Walker is a Visiting Fellow, Australian National University

Original article: https://theconversation.com/more-than-10-000-job-losses-billions-in-lost-revenue-coronavirus-will-hit-australias-research-capacity-harder-than-the-gfc-138210

Index of Advertisers

Corporate Member Address List

Coherent Scientific Pty Ltd
116 Sir Donald Bradman Drive
Hilton, SA, 5033
Tel: (08) 8150 5200
Fax: (08) 8352 2020
sales@coherent.com.au
www.coherent.com.au

Lastek Pty Ltd
10 Reid Street
Thebarton, SA, 5031
Tel: (08) 8443 8668
Fax: (08) 8443 8427
sales@lastek.com.au
www.lastek.com.au

LightOptronics Aust.
29 Pitcairn Circuit
Seaford Rise, SA, 5169
Tel: (08) 8327 1885
rons@lightoptronics.com.au
www.lightoptronics.com.au

Miriad Technologies Pty Ltd
36 Bradfield Road
Linfield NSW, 2070
Tel: +61 415 942 644
sales@miriad.com
www.miriad-tech.com

Photon Scientific
Mulgrave, VIC, 3170
Tel: +61 8502 6393
sales@photonscientific.com.au
www.photonscientific.com.au

Raymax Lasers Pty Ltd
37/5 Ponderosa Parade,
Warriewood, NSW, 2102
Tel: (02) 9979 7646
Fax: (02) 9979 8207
sales@raymax.com.au
www.raymax.com.au

SPIE
PO Box 10
Bellingham WA 98227-0010 USA
Tel: +1 360 676 3290 or +1 888 504 8171
Fax: +1 360 647 1445
customerservice@spie.org
www.spie.org

Warsash Scientific Pty Ltd
PO Box 1685, Strawberry Hills
NSW, 2012
Tel: (02) 9319 0122
Fax: (02) 9318 2192
sales@warsash.com.au
www.warsash.com.au