OPTICS & PHOTONICS NEWS

JUNE 2020

OPTICAL NEURAL NETWORKS 32

2020 OSA AWARDS AND MEDALS 40

TAILORED FOR PURPOSE

Structured Light

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OUR RESPONSE TO COVID-19

Dear OSA Member:

Words like “unprecedented” and “surreal” come to mind in describing the current health crisis impacting communities in every part of the world. As someone who looks for silver linings, I am inspired by the game-changing technologies in optics and photonics being developed and deployed by our members. These advances are helping to overcome tremendous obstacles resulting from the COVID-19 pandemic. Our scientific community is an integral part of the solution.

We are learning to communicate and do business in innovative ways that will be a big part of the new normal going forward. I am proud of how your OSA team continues to support our community with agility, innovation, and real-time results.

In early March, with little more than a week’s notice, we transformed the OFC co-sponsored conference in San Diego, CA, USA. Over 90% of the 700 talks were presented, both in-person and virtually. Coming on the heels of OFC, OSA’s Leadership Conference in March was held virtually to ensure that governance decisions and priorities were delivered. Almost all OSA Congresses scheduled through July, plus OSA’s co-sponsored CLEO conference being held in May, will be freely accessible online to all registered attendees.

Our goal is to ensure that you continue to have the necessary support to advance your research, applications and careers.

All of us at OSA are focused on delivering technical content, products, programs, benefits and services with minimal disruptions. Our goal is to ensure that you continue to have the necessary support to advance your research, applications and careers. To learn more about how our programs are retooling to meet our community’s needs, visit OSA’s We Are On webpage at **www.osa.org/WeAreOn**. And as always, our door is open—please let us know how we can better serve you and our community at **WeAreOn@osa.org**.

Digital technology is enabling us to collaborate and form new partnerships. Our promise to you—we will continue to develop and package virtual content to make it easier for you to remain engaged with and inspired by your colleagues. Looking ahead, we know how important it is for our community to gather in person; OSA will be ready to host you and your colleagues when the time is right.

I hope you and your home and work families are safe as we ride out the storm. Together we can create those new silver linings. Focus on the miracles sparked by our virtual connections and your ingenuity, and navigate it all with a healthy dose of humor. I am confident we will emerge from this pandemic as a stronger worldwide community of leaders bringing light into the world.

—Yours Respectfully,

Elizabeth Rogan, OSA CEO

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FEATURES JUNE 2020

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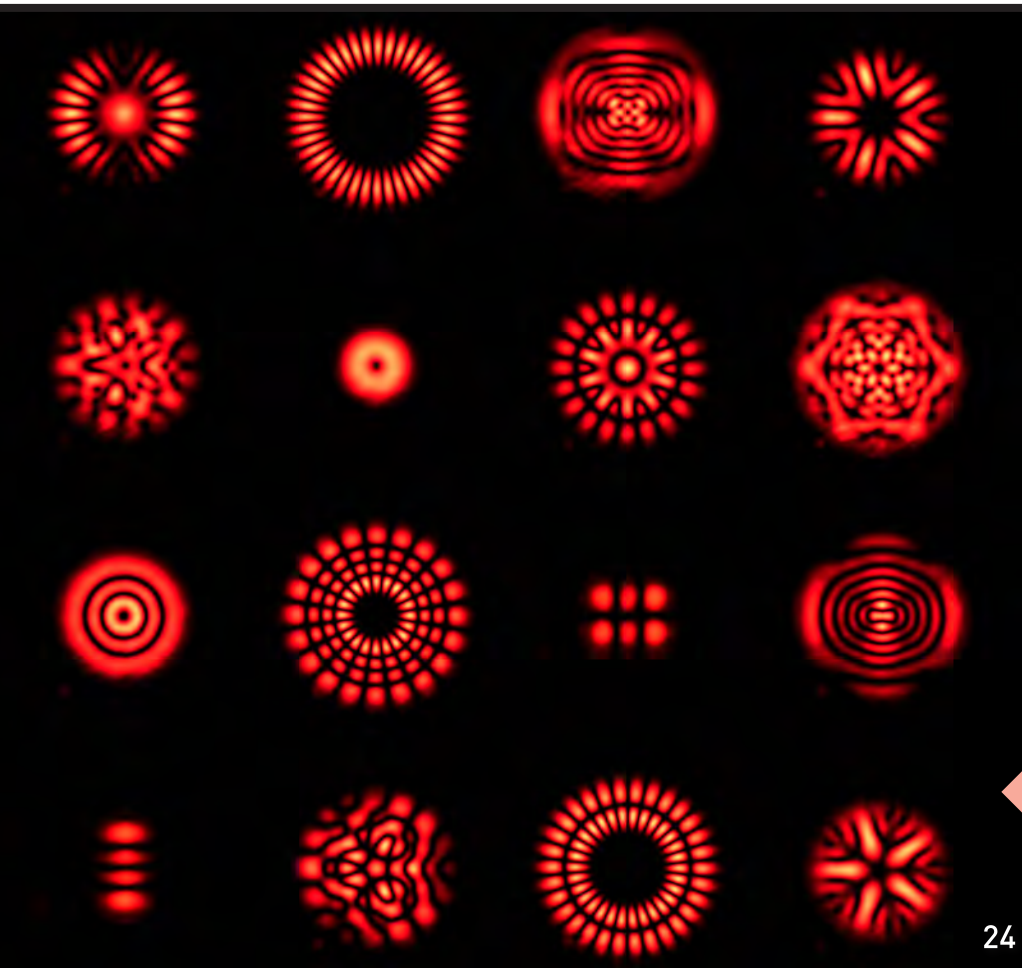
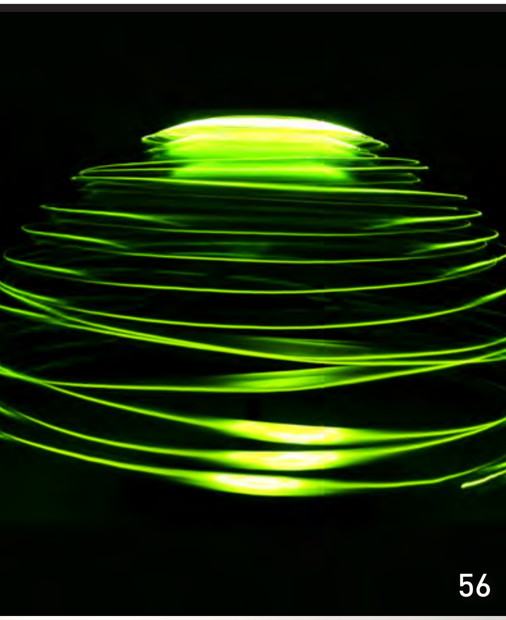
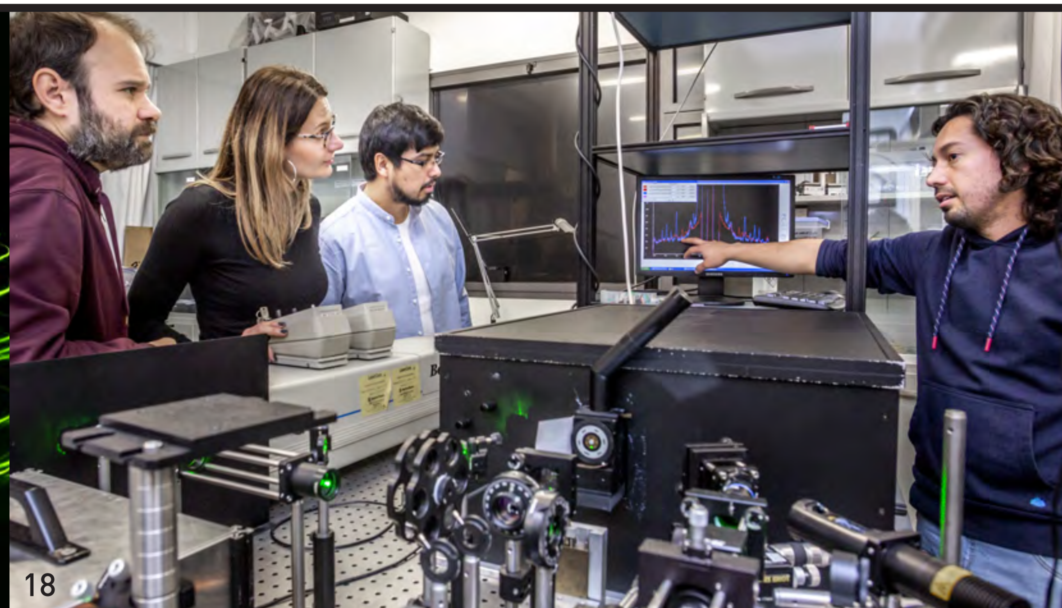


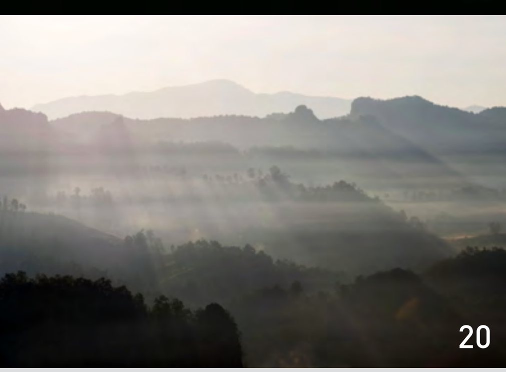
Tools for controlling light amplitude and dynamic and geometric phase create a widely varied menu of structured light.

OPTICS & PHOTONICS NEWS

DEPARTMENTS







COVER: Shaping of light with tools such as custom metasurfaces can create beams tailored for specific purposes, like the twisted OAM modes shown in this artist's rendering. Our update on structured light begins on p. 24. [University of the Witwatersrand]

President's Message

In this issue of *Optics & Photonics News*, we highlight 24 winners of 2020 OSA Awards; additional awardees will be honored later in the year. I would like to congratulate these accomplished individuals for the creativity and extended dedication to their fields that the awards recognize.

At the same time, thousands of those newly entering our field—our student members—will have to forego the recognition and celebrations that usually accompany college graduations each June. This year is different, but the ceremonial aspect of noting these achievements is more important than ever.

I do think, however, that the current situation offers new ways to celebrate that move the focus from solely the graduates themselves, to include those who helped make their success possible. At the time of my college graduation, it was, for me, just something to get to and get through before moving on to the bigger things that awaited. I did not appreciate then how important the milestone was to those who helped in my achievement—my parents, teachers, friends and mentors.

Resiliency is a trait that anyone can develop and use in tough times throughout life.

While this year's graduations may not have the pomp and circumstance of previous years, the once inconceivable situation we now find ourselves in does provide an opportunity to more seriously consider this important milestone. For this year's graduates, I congratulate you and those who helped you along the way. Take a moment to thank them—a relative, partner, spouse, friend, teacher or mentor; or perhaps someone who inspired you at a very early age. This unexpected gesture is something that you can give to mark the occasion together with those who helped make it possible.

These interactions individually may seem small, but they often lead to serendipitous conversations and connections that help build a community and a social and professional network. Together they build our communal resiliency, something that we don't pay much attention to except in times of crisis.

Adapting to a changed environment or any traumatic event challenges us and tests our resiliency—our capacity to cope with and adjust to change. Challenges that may seem overwhelming, when met head-on, can bring important personal growth. Resiliency is a trait that anyone can develop and use in tough times throughout life. And one of the key strategies is to make your relationships and your community a priority, and a mutual source of social support.

At The Optical Society, our organizational resiliency, the ability of OSA and its staff to weather the storm, speaks to the society's financial, operational and cultural assets. I am happy to report that OSA's strong financial reserves and personal commitment of staff and members have enabled it to focus on keeping our community strong by meeting challenges, closing ranks and adapting to change as never before.

As we meet challenges today, our resiliency as individuals, communities, and organizations builds, helping us to emerge stronger. I wish you well as you face your own set of challenges—as well as a lifetime of good things small and large to come.

—Stephen D. Fantone,
OSA President

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Contributors

Structured Light

In June's cover feature, OSA Fellow **Andrew Forbes**, University of the Witwatersrand, South Africa, explores the field of structured-light research. "I believe that we have not yet exploited the full potential of structured light to control matter," Forbes says. He predicts growth will be in structured light's interaction with structured matter. "The quantum direction holds tremendous promise," Forbes notes. "The toolkit for controlling high-dimensional states of light is largely empty, but sure to fill with the billion-dollar-scale investments in quantum technologies worldwide."

Optical Neural Networks

In a second feature, freelance science journalist **Edwin Cartlidge** delves into optical neural networks. Cartlidge notes that some recent work using phase-change materials "seems to provide a neat way of overcoming ... nonlinearity." He also finds the work of Jeffrey Shainline, NIST, USA, "particularly intriguing." While he acknowledges that the work is long term in nature, "it is certainly ambitious—with the aim to build a network with billions of neurons. Given that that would be brain-scale ... it will be interesting to see just what processing powers such a network posseses."

2020 OSA Awards and Medals

Meredith Smith [pictured] of the OSA Awards Office worked with **Kari Apter** and **Samantha Hornback** to compile this year's feature recognizing members of the optics community for their contributions to science, research, engineering, education, industry and society. This year, "six women have been selected as award/medal winners ... a historic high for OSA," Smith says. Due to the pandemic, OSA is "incorporating more video remarks into our award presentations, and have recognized honorees on banner ads during virtual meetings. We continue to look for opportunities to recognize and celebrate our award winners, even if we can't be in the room together."

More Lasers!

The cover article of OPN's May issue, "The Laser at 60," offered a look at the rich field of lasers. If you enjoyed this article, be sure to check out the additional resources page (**www.osa-opn.org/link/laser-at-60**), for extended interviews with several of the OSA Fellows who are working with laser technology. And for those interested in additional reading on lasers, the page also includes links to the articles referenced in the feature article as well as a selection of laser history articles that have been published in OPN.

tweeted

@QiwenSt (Qiwen Su)

Freshman yr in undergrad, I left a vial opened for a month. Surprisingly, exposing to air that long, I got a purer and more products than ever reported!! AND a first author publication. Accidents lead to small discoveries

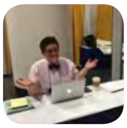
@NoraSci (Nora Bailey)

It is known that anything you do while waiting for code to run counts as working. Today that included walking to Starbucks, learning a new TikTok dance, and looking at new 23andme reports. #phdchat

@perkovictoria (Victoria Perko)

I used to sign emails Happy Tuesday, as a cheerful alternative to Best, or Thanks, but now it just feels like I'm bragging about knowing what day it is #AcademicChatter

@carytrump (Cary Trump)



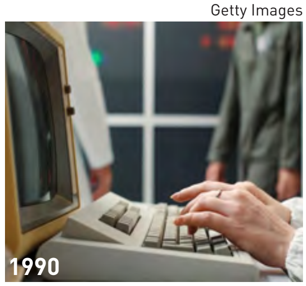
I modified a discussion board post to include an option of submitting cute animal pics. As a result, my students are randomly emailing cute animal pics. So I'd say that was the best professional decision I've ever made. @AcademicChatter #AcademicChatter #AcademicTwitter

30, 20, and 10 Years Ago in OPN

"Electronic methods of communication are beginning to enhance and, in some cases, replace communication via printed paper. Facsimile machines are in constant use throughout the world, electronic mail is used instead of paper letters, literature searches can be performed from any phone line, and entire journal volumes can be obtained on CD ROM … The most difficult problem you will encounter in sending E-mail is in providing a complete and accurate address for your recipient … including the names of the user, host computer, institution, and network."

"E-mail: At your fingertips if you have a PC," *Optics & Photonics News*, June 1990, p. 43

Getty Images



"The Army needs to find new fire suppressants that will work quickly, produce a minimum of toxic gases, be compatible with storage materials, and meet environmental safety standards … To assist in the testing and evaluation of halon replacement agents, the ARL group has performed research using two optical sensing techniques: laser-induced breakdown spectroscopy (LIBS) and near-infrared tunable diode laser absorption spectroscopy (NIR-TDLAS) … [A] TDLAS-based HF chemical sensor for use in full-scale fire suppression testing of various halon alternatives … allows for real-time measurement of HF concentrations down to the parts-per-million level."

"Optical R&D at the Army Research Laboratory," *Optics & Photonics News*, June 2000, p. 16

Doug Lefon

"The ideal diagnostic modality would be noninvasive and would produce quick, accurate information in clinical settings. A new approach called interferometric synthetic aperture microscopy (ISAM) provides a means of retrieving high-resolution images from entire tissue volumes. The hardware used in ISAM originates from optical coherence tomography (OCT), a low-coherence interferometric ranging technique with micrometer-resolution and deep penetration within tissues (on the order of 2 mm). ISAM data processing is an optical analogue of synthetic aperture radar (SAR)."

"Interferometric synthetic aperture microscopy: Microscopic laser radar," *Optics & Photonics News*, June 2010, p. 32

Fran Harrington

Please direct all correspondence to the Editor, OPN, opn@osa.org.

OSA Awards and Medals

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Researchers have built a new integrated circuit to implement measurement-device-independent QKD.

Henry Semenenko, University of Bristol

SECURITY

A Chip to Battle Quantum Hackers

Compact photon sources enable measurement-device-independent quantum key distribution

A University of Bristol, U.K., team has shown how integrated photonics could enable quantum key distribution (QKD) using small, robust and relatively cheap semiconductor chips (Optica, doi: 10.1364/OPTICA.379679).

QKD involves two people—nicknamed Alice and Bob—sharing a secret string of bits to encrypt and decrypt messages. Although uncrackable in principle, QKD is in practice vulnerable to attacks in which hackers create hidden "side channels" to siphon off the secret information.

Recent research has shown how microchips can be used to make the photon sources needed in a scheme devised to combat attacks against detectors known as measurement-device-independent QKD. The scheme involves both Alice and Bob sending independent bit strings not to each other, but to a third party, nicknamed Charlie.

The Bristol team made Alice and Bob's photon sources from 6×2-mm indium phosphide chips that contain a series of Mach-Zehnder interferometers and other optical components. The researchers sent weak pulses of photons down a fiber link whose length they represented using a variable attenuator. They encoded signals using photons' time of arrival and phase, and detected those signals using superconducting nanowire single-photon devices.

The team was able to transmit information with a quantum bit error rate of less than 0.5%. —*Edwin Cartlidge*

www.osa-opn.org/news/chip-enables-qkd

MATERIALS

Toward Sustainable Wearable Tech

Flexible, clear substrate made from waste fish scales could replace the plastic films in light-emitting devices

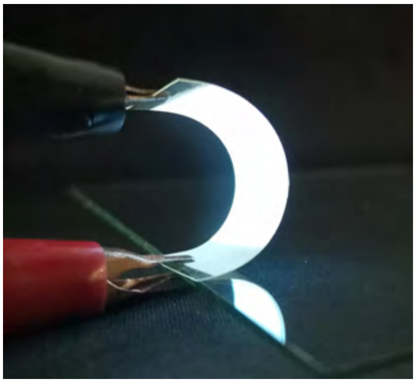
The possible impact of plastic films in optoelectronic devices—particularly in disposable wearable technologies under development—has started to raise concerns. A research team in China now offers one possible answer: Make the films out of fish scales (ACS Nano, doi: 10.1021/acsnano.9b09880).

The team focused on the transparent plastic films used in flexible alternating-current electroluminescent (ACEL) devices. ACELs are particularly attractive for wearable tech, and could one day be used for a new generation of single-use, "electronic skin"-type applications.

A main component of these envisioned single-use wearable displays is thin, flexible plastic substrates. These materials are created from nonrenewable fossil-fuel feedstocks, and their production contributes nontrivially to climate change. Also, the discarded plastics could add to the impact of plastic waste in the environment.

The researchers wanted to find an alternative substrate material for optoelectronic-skin applications that might carry less of an environmental punch; they settled on gelatin from fish scales. The material sports some potentially good optoelectronic qualities, it's biodegradable, and a huge amount of waste fish scales is available as raw material.

The researchers began by washing and chemically pre-treating fish scales to create a precursor solution, which they cast in a petri dish into films made of fish-scale gelatin. Tests revealed that the clear film sported up to 91.1% transmittance across the visible spectrum—slightly better than PET films. The films also showed good flexibility and could even be reversibly folded. And the team found that the film was easily recyclable and biodegradable.



A team in China designed a fish-scale gelatin film for use as a substrate for several luminescent devices.

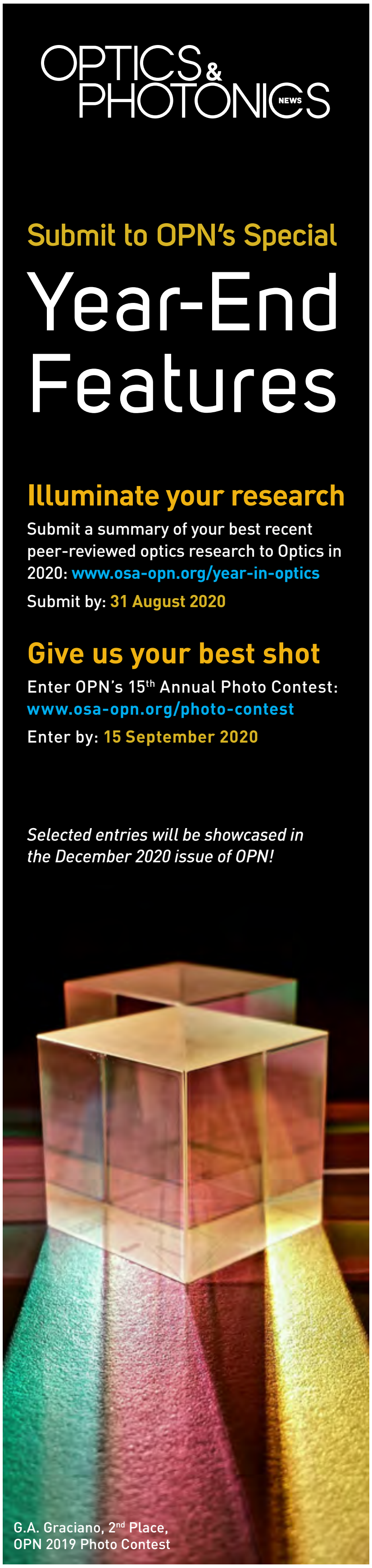
ACS Nano, doi: 10.1021/acsnano.9b09880 (2020)

The team next used the film as a substrate for several luminescent devices. It found that the stack glowed brightly under applied alternating current—with "no significant drop in emission intensity" even after 1000 cycles of bending and relaxing.

The team believes its films could have a future in wearable tech as well as flexible displays. —*Stewart Wills*

www.osa-opn.org/news/fish-substrate

Inedible waste fish scales account for about **3%** of the annual production of **70.5 million** metric tons of fish.



Allison Kalpakci

PHOTOVOLTAICS

Underwater Energy

Researchers in the U.S. have demonstrated the vast potential of underwater solar cells made with wide-bandgap semiconductors (Joule, doi: 10.1016/j.joule.2020.02.005).

Most of the world's solar cells are made of silicon, but its relatively narrow band gap prevents it from absorbing enough sunlight when submerged.

The team wanted to outline specific guidelines for materials that would create the best possible underwater solar cells, so it used a theoretical model to calculate the ultimate efficiency limits for underwater cells made with optimal materials. The model takes into account the bandgap energy of the semiconductor, depth below sea level, light absorption of the water and other factors.

By sifting through oceanographic data, the researchers found that when going from shallow (2 to 4 meters) to deeper waters, the ideal band gap shifts from 1.8 eV to 2.4 eV, with a plateau at 2.1 eV between 4 and 20 meters.

The team determined that underwater solar cells made with optimal materials can exhibit efficiencies of approximately 55% in shallow waters to more than 65% in deep waters. —*Meeri Kim*

www.osa-opn.org/news/underwater-solar

IMAGING

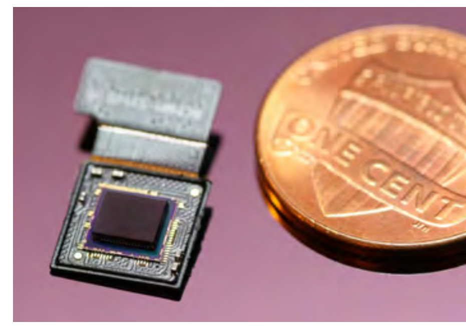
Thin High-Resolution Camera

Like the compound eyes of insects, cameras with arrays of small lenses can produce wide, sharp images. Researchers at a South Korean university have devised an extremely thin but fully packaged camera that is smaller than many coins (Light Sci. Appl, doi: 10.1038/s41377-020-0261-8).

The camera uses arrays of tiny optical elements above a planar CMOS sensor to achieve high resolution and a 73° field of view with just 740 μm of total track length, or space between the sensor and the end of the lens system. A super-resolution algorithm assembles the images from each lens channel into a single finished product.

The researchers studied the eyes of *Xenos peckii* for inspiration. The insect's hundreds of "eyelets," with relatively large lenses, each detect a partial, overlapping image within its field of view, providing the parasite with 50 times better spatial resolution than the conventional compound eyes of arthropods.

In 2018, the team demonstrated an earlier version of its parasite-inspired thin camera. The new camera cut the track length nearly in half by inverting the arrayed microlenses to increase their refraction. Each lens had an f-number of only 1.7.



Ki-Hun Jeong, KAIST

Various photolithography processes created the tiny transparent-resin arrayed lenses. Tests with a 532-nm laser beam showed a lack of optical crosstalk between the microlenses.

The team hopes that this type of thin camera will lend itself to biomedical and security applications. —*Pat Daukantas*

www.osa-opn.org/news/thin-cam

In the Spotlight ...

Here is some interesting research recently highlighted in OSA Publishing's *Spotlight on Optics*:

Daniel Diaz and David W. Hahn look at an *Applied Optics* study in which **laser-induced fluorescence spectroscopy and imaging** are used to describe the properties of fuel, water and ethanol emulsions.

Mariia Kramarenko highlights an *Optics Express* paper that proposes to **mitigate reflection losses in perovskite/c-Si tandem photovoltaics** by implementing nanostructured front electrodes.

For more on this and other research in the spotlight, check out **www.osapublishing.org/spotlight**.

LASERS

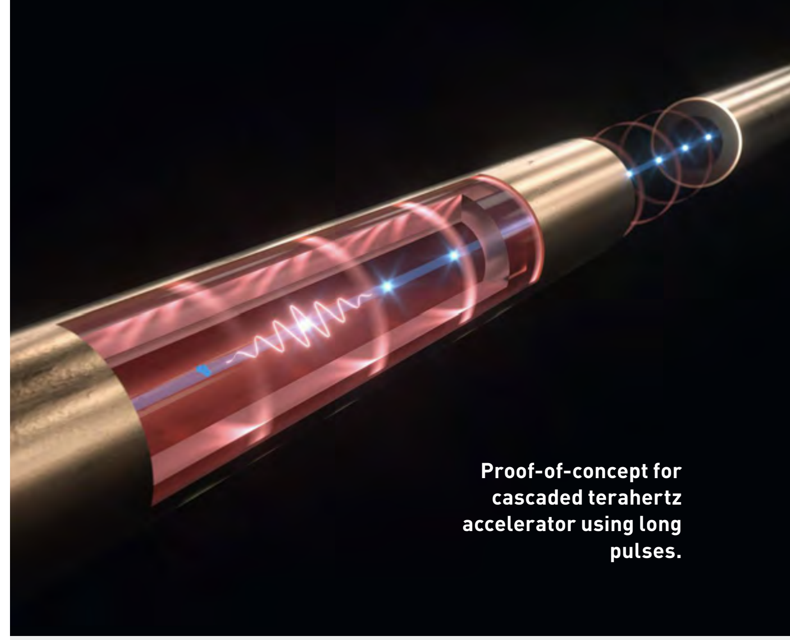
Accelerator Doubles Down

A group at Germany's DESY particle accelerator facility has developed a proof-of-concept miniature particle accelerator that can recycle laser energy fed into the system to give the energy of accelerated electrons a second boost (Phys. Rev. X, doi: 10.1103/PhysRevX.10.011067).

The new device is just 1.5 cm long and 0.79 mm in diameter, a miniature size made possible by terahertz (THz) radiation's short wavelength. Scaling accelerators to THz frequencies allows for greater acceleration gradients.

The researchers assembled a 53-keV phototriggered DC gun as an injector for the multi-staged, dielectrically lined waveguide (DLW)-based electron accelerator and manipulator, which is powered by narrowband, multi-cycle THz pulses.

The way it works is that the researchers feed a multi-cycle THz pulse into the DLW, which reduces the speed of the pulse. Then, electrons are shot into the central part of the waveguide to travel along with the pulse, creating the first electron energy boost. Because the electrons travel in the nonrelativistic regime, this enables recycling of the THz pulse for a second stage of acceleration.



Proof-of-concept for cascaded terahertz accelerator using long pulses.

DESY, Science Communication Lab

Once the THz pulse leaves the waveguide, it enters a vacuum, its speed is reset to the speed of light, and the pulse overtakes the electrons in just a few centimeters. The pulse then encounters another waveguide that slows its speed, creating an interaction section to boost the electron energies a second time.

According to the authors, the device shows electrons can gain energy in the waveguide. A stronger laser, they say, could deliver stronger acceleration. —*William G. Schulz*

www.osa-opn.org/news/thz-driven-accelerator

Where Science + Applications Intersect

EXTENDED POSTER SUBMISSION DEADLINE: 14 July 2020

ADVANCE REGISTRATION DEADLINE: 17 August 2020

The conference will be held as scheduled. We continue to monitor advisories related to COVID-19, and commit to being responsive amidst changing conditions to facilitate maximum participation for speakers, attendees and exhibitors while ensuring the well-being of all participants.

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BIOLOGY

Modified LCDs Test Color Vision

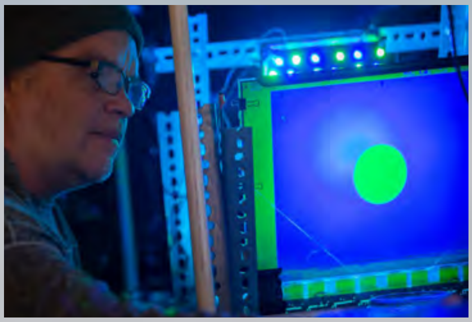
Researchers have altered computer displays to better test color vision in crabs

Understanding how animals see the world can be valuable to researchers. But simulating animal vision can be difficult if the tools you are using are specifically designed for the human visual system.

Now, researchers in the U.S. have modified simple, inexpensive liquid crystal displays (LCDs) to better test color vision in animals without needing prior knowledge of the animal's photoreceptor sensitivities (Methods Ecol. Evol., doi: 10.1111/2041-210X.13375).

An old LCD computer monitor formed the basis for the setup, keeping costs down. The team took apart the monitor and replaced the front polarizer (on the viewing side) and added two diffusers. They then backlit the screen with two different colors of LEDs, blue and green.

To test their device, the team set up an experiment with crabs to measure their escape response to a dichromatic looming stimulus—a video of a fast-approaching circle appearing on the screen. This two-LED configuration tested the crabs' color discrimination, while a one-LED configuration tested color sensitivity.



Biologist John Layne with the modified LCD setup.

A. Higley/ UC Creative Services

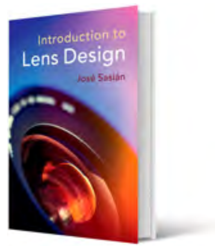
The researchers hope that the setup will allow for more accurate testing of color's role in visually guided behaviors by allowing for greater control over the wavelengths and intensity of visual stimuli. —*Molly Moser*

www.osa-opn.org/news/lcd-color-vision

Getty Images

BOOK REVIEWS

Introduction to Lens Design



J. Sasián, Cambridge University Press, 2019

This book's strength lies in delivering a vast amount of knowledge on optical lens design in a succinct manner. It comprehensively describes the fundamental optical theory and state-of-the-art of lens design, including aberrations, achromatic doublets, and lens tolerances. This field has strong impacts in several technologies from telescopes to lasers to microscopes. The book's target audience is graduate students in optical design and photonics engineers. —*Christian Brosseau*

Glass Micro- and Nanospheres

G.C. Righini (Ed), Jenny Stanford Publishing, 2019

The editor and his collaborating authors have written a state-of-the-art reference on micro- and nanospheres with applications in physics. Beyond an introduction to whispering-gallery modes, the reader can easily progress to applications in high-resolution biosensing for detecting molecules, viruses and biomarkers. Also, the development of microsphere lasers, glass beads and ball lenses should attract a wide readership. —*Axel Mainzer Koenig*

The New International System of Units (SI)

E.O. Gobel and U. Siegner, Wiley-VCH Verlag GmbH, 2019

This book contains a complete review of the revised SI, which came into force in 2019. It is based on a previous book by the same authors, but it is revised with new SI definitions and the differences between the previous and the present SI. The book explains and illustrates the physics and technology behind the definitions and their impact on measurements, emphasizing the decisive role quantum metrology has played in the revision. —*Reva Garg*

A Practical Guide to Optical Microscopy

J. Girkin, CRC Press, 2019

This is an agile volume that brings the reader from the basic fundamentals of microscopy to modern techniques such as advanced wide-field microscopy, confocal microscopy, fluorescence-lifetime imaging, light-sheet and selective-plane microscopy, and multiphoton fluorescence. A distinctive feature is the guide the book offers for making optimal use of the instrument and developing research protocols. —*Silvano Donati*

Christian Brosseau, Université de Bretagne Occidentale, France. Axel Mainzer Koenig, CEO, Mainzer Koenig Research Associates, USA. Reva Garg, Institute of Physics, University of Brasilia, Brazil. Silvano Donati, University of Pavia, Italy.

DEVICES

MOF-Based Broadband Photodetector

Metal-organic frameworks (MOFs) have been proposed as a possibly cheaper alternative to traditional semiconductor materials. Now, a team from Germany and Spain has reported a MOF-based photodetector that can detect a broad spectral range extending from blue to near-infrared without losing functionality (Adv. Mater., doi: 10.1002/adma.201907063).

MOFs are highly regarded for their tunability, structural diversity, and subsequently wide range of chemical and physical properties. In 2018, the team created 2D semiconducting MOF thin films. In the most recent work, they set out to build a photodector with those films.

To synthesize the MOF layer, iron atoms and organic ligands were bonded with sulfur in a honeycomb structure. The researchers then used electron-beam lithography to fabricate indium metal electrodes directly onto the MOF sheet, which was affixed to a glass substrate.

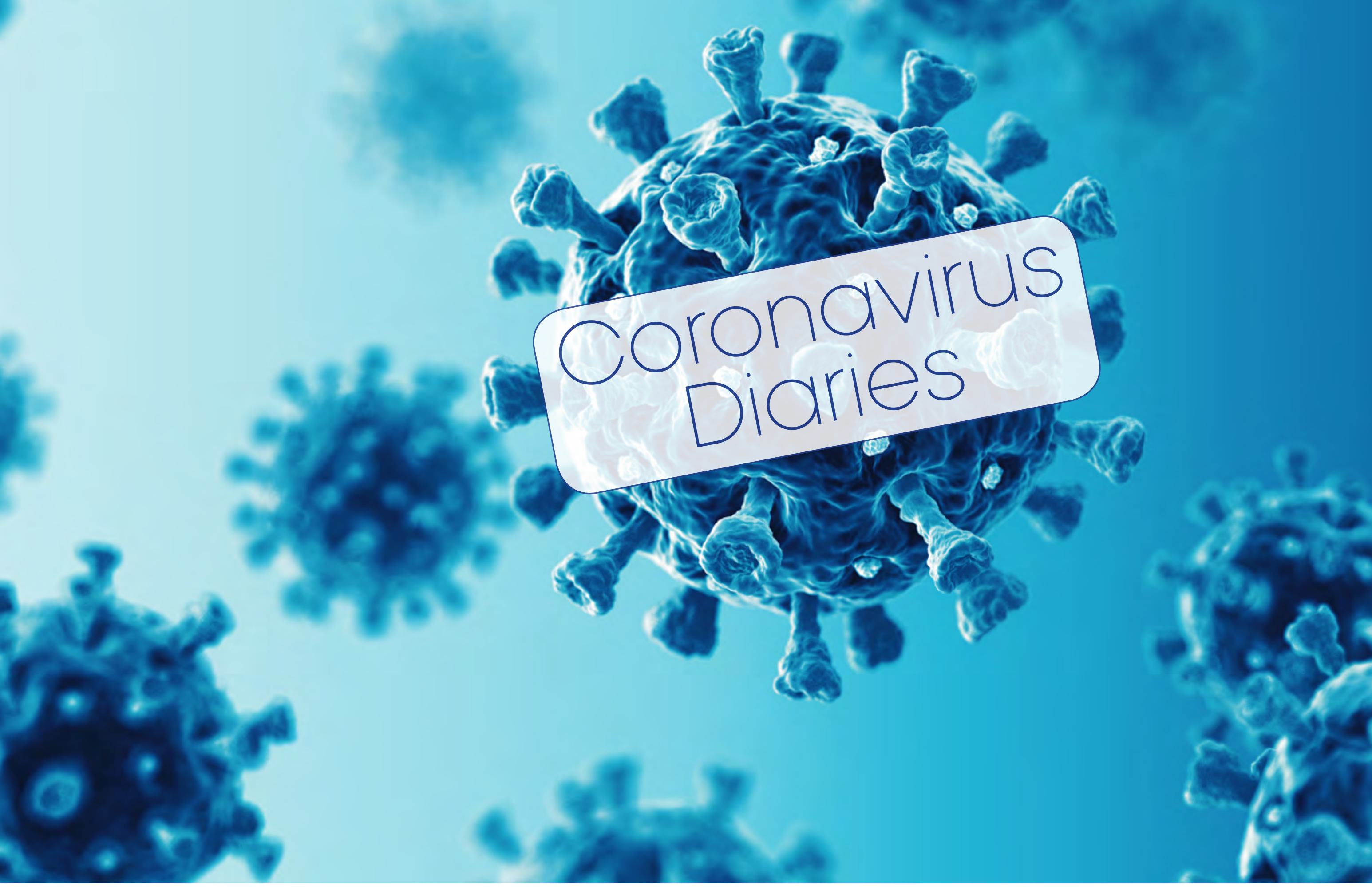
They tested the photoresponse of the MOF-based detector to laser light at various wavelengths, and checked its functionality at different power settings and temperatures.

The work demonstrates the feasibility of integrating MOFs as an active element into most cost-effective photodetectors. —*Meeri Kim*
www.osa-opn.org/news/MOF-photodetector

HZDR / Juniks

Patricia Daukantas, Edwin Cartlidge, Meeri Kim and William G. Schulz are freelance science writers. Molly Moser is OPN's associate editor. Stewart Wills is OPN's senior editor. Alessia Kirkland is OPN's creative director.

Pulses



Getty Images

CONVERSATIONS

Coronavirus Diaries

Members of the optics and photonics community share how the COVID-19 crisis has affected their lives and work, and what the pandemic means for photonics.

As the coronavirus crisis has unfolded during early 2020, the optics and photonics world has felt its effects. In March and April, OPN interviewed nine professionals to learn more about the pandemic's impact on our community. The interviewees spanned multiple countries, research fields, industries and career stages—each offering a different perspective on the ways their lives and work have changed, what a recovery from the crisis might look like, and the future of optics and photonics in a post-COVID-19 world.

Read the full interviews online: www.osa-opn.org/coronavirus_diaries.

Ian Walmsley

2018 OSA President, Provost and professor of experimental physics at Imperial College London, U.K. [Interviewed 1 April]

Q. How has the pandemic affected you as a decision maker? Will this impact long-term plans for your institution?

The situation changed very rapidly, requiring us to move at an extraordinary speed from normal operations to complete remote working. All of the effort that we were thinking about—about planning for the future, the big academic strategy, the state investments and the great things we wanted to do—are now on hold. Now we're retrenching finances for a world where cash flow is important and liquidity is the key thing to keep us going until we know what the other side of this looks like. It's a real change of focus from bigger-picture thinking to day-to-day decision making.

Soon we'll have to start thinking about, What does the world look like next year? And the year after that?

If, for example, overseas students decide that they're just going to stay closer to home because international study is too big of a risk, then that fundamentally changes the face of higher education—not only in the U.K., but globally. Then remote education comes into its own.

Q. What have you learned about remote learning as all of this has unfolded?

At the moment, there's a great deal of experimentation. But certainly, some of the practices that we've seen around campus for building learning communities—which are effective, rather than just delivering lectures online—are techniques that can really add value to teaching.

What we haven't fully figured out yet is understanding how that works in the long term. What is the importance of the in-person contact in education versus complete remote learning? They're ongoing experiments, but as with all experiments, the outcome is quite exciting when you don't know what it is.

We see a lot of opportunity arising from this experience and expertise as we look forward to next year.

“It's a real change of focus from bigger-picture thinking to day-to-day decision making.”

—Ian Walmsley, Imperial College London, U.K.

“I hope this crisis will open new paths and new positions that we couldn't imagine before.”

—Andrea Pacheco, Tyndall National Institute, Ireland

Andrea Pacheco

Ph.D. student from Colombia, completing her biophotonics studies at Tyndall National Institute, Ireland. [Interviewed 14 April]

Q. You're finishing up your Ph.D. Is this a particularly bad time to have your research halted by a pandemic?

Yes, it is. Usually, as researchers, we tend to have everything planned—this is a gigantic turn of events that we didn't expect at all.

I'm also thinking about what will happen after I get my Ph.D. Before, I was looking at other European countries for my postdoc, and I was considering applying to positions in industry. Now, I don't know. If there are new policies from the E.U., then how will they affect immigrants like me? On top of that, there will definitely be a lot of people losing their jobs. Will there be more positions?

Q. As someone who is thinking about starting her career, what are your thoughts about the future?

The world as we knew it is not coming back. I hope that this crisis will open new paths and new positions that we couldn't imagine before. We've proven that we can work from home effectively, so perhaps there will be more possibilities to collaborate and do research together from different parts of the world.

This is something that is already happening—there are so many researchers linked together by the common goal of solving the pandemic. This is a nice model of what we can do as researchers on a global scale—the virus is making us a bit more human and making us think globally.

COVID-19 at All Career Stages

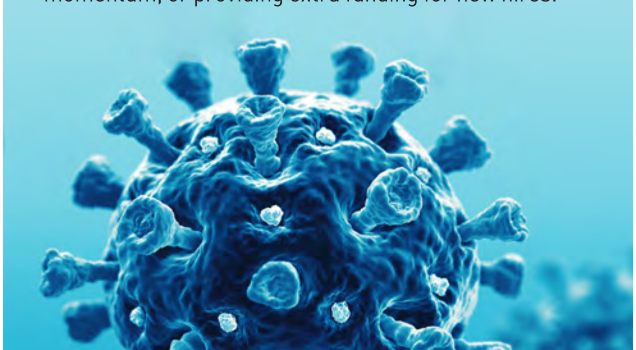
Across the interviews in this series, one recurring theme was the disproportionate toll that coronavirus will likely take on students and early-career researchers. Of the more senior optics and photonics professionals that OPN spoke with, many viewed the pandemic and its consequential countrywide lockdowns as unfortunate delays for their research. However, they, along with the more junior researchers and students, expressed concern over the larger impact of such delays on the younger optics and photonics community.

The student perspective: Although many research teams may be coping well as a whole, as Roberta Ramponi at Politecnico di Milano, Italy, notes, "you have some situations that may be difficult." Ramponi cited an example of a Ph.D. student who was unable to travel to Israel and take the measurements that she needed to finish her thesis—"that's quite a mess."

Lost time: The students who were just beginning and those who were about to move on, OSA Ambassador Manish Tiwari notes, will be the most affected. At Manipal University Jaipur in India, some students are confiding to Tiwari their worries that they'll be set back a full year. "I'm encouraging them that we'll try to cope with this delay," he says. "But, on the other hand, I know that the time that we've lost is gone."

Lost opportunities: Another area of concern, according to Rocío Borrego-Varillas, Politecnico di Milano, is the string of canceled conferences and events, which students depend on for both education and networking. To address this, she, as part of the Ultrafast Optical Phenomena OSA Technical Group, is organizing a series of online events oriented for undergraduate and Ph.D. students—"similar to a virtual 'summer school.'"

Mitigating the fallout: "Unless measures are put into place to really support younger researchers," says John Dudley, Université Bourgogne Franche-Comté, France, "then I think that many early-career researchers may well see their careers suffer." Such support steps, he suggests, might include taking away teaching responsibilities for a few months to let young researchers regain momentum, or providing extra funding for new hires.



> "Long-term planning is difficult because you need to plan for uncertainty."
> *—Simin Cai, Go!Foton, USA*

Simin Cai

President and CEO of Go!Foton, USA, and OIDA Council Chair. [Interviewed 20 April]

Q. How has your response to COVID-19 evolved? What areas or sectors have been most affected?

Geographically speaking, I think the impact is like a wave—different areas at different times. We have a subsidiary in Nanjing, China, and a plant in the Philippines, so the first thing we thought about was about the safety and the security of our people over there. We started working from home; we tried to put everything remote, and we tried to gather some facemasks for our employees. In the meantime, we worked to secure the supply chain.

Our key vertical market we serve is in the telecommunication/optical communication area. So, at least so far, we haven't seen any slowing down on the demand side, and in some areas we're actually seeing some growth.

Q. What are a few of the immediate challenges facing optics industries during this time?

The immediate challenge, except for those serving essential businesses or communications, will be that demand will have a pretty significant drop, and then the cash flow, supply chain and employee issues and so on. During an OIDA webinar, I encouraged companies to engage with the community and with their employees. And then to work on collecting the "collective wisdom" within our community to address those challenges.

Long-term planning is difficult because you need to plan for uncertainty. You don't know what's going to happen—so prepare for the worst, then work for the best.

Jian Wang

Professor at Huazhong University of Science and Technology in Wuhan, China. [Interviewed 21 April]

Q. How has this crisis affected life in Wuhan?

It is certain that COVID-19 has caused a great impact on our lives and work—including my own research and lab. All experimental work—fabrication of optoelectronic devices, experiments of optical communications, etc.—stopped.

Even with the return to work, production and school, the whole society has been paying attention to the prevention and control of COVID-19. Its also strengthening its examination of asymptomatic infection ... I believe that for the people of Wuhan, the darkest period has passed.

Q. Wuhan is considered China's "Optics Valley." How has the pandemic affected optics there?

Personally, I think the larger picture of optics and optoelectronics in Wuhan will be "Wuhan—World Optics Valley," similar to the Silicon Valley in the United States.

> "The lockdown pressed the "Pause" key. After the re-start, activities will recover slowly."
>
> —*Jian Wang, HUST, Wuhan, China*

The lockdown pressed the "Pause" key temporarily, and after the re-start [in April], activities will recover slowly.

To bring research and industrial activity in optics back up to speed in the wake of the disruption, I personally believe three things are needed: city functions need to be repaired first, so that research and industrial activity in optics can quickly return to normal; more preferential policies are needed to support small- and medium-size enterprises of optics and optoelectronics; and more appealing initiatives are needed to attract graduates to stay in Wuhan and build Wuhan.

Everything has two sides … People in China will be more united after COVID-19. I do believe everything in Wuhan, including Optics Valley, will go well and even better with the hard work of all people in Wuhan.

> "Whatever science funding there will be, the photonics world is well positioned."
>
> —*Michal Lipson, Columbia University, USA*

Michal Lipson

Professor of applied physics at Columbia University, New York City, USA. [Interviewed 22 April]

Q. You work in New York City—the U.S. epicenter for this infection. What has this meant for your group?

When you go out in the streets here, it's very eerie. It feels like the Gulf War in Israel, which I went through. Because it's the same sense, that the world will never be the same.

I absolutely never would have chosen this. But the good side is that to do a pause, and to think, to work more heavily on theory and design, to understand the data, or even to understand simulations, come up with new ideas—that is an opportunity. Hopefully, it's not all lost.

Q. What sort of long-term effects might this experience might have?

If we're looking for a silver lining, now more than ever, communication, in which photonics is a very big player—if not *the* player—is clearly a major priority. Sensing, another area where photonics is important, might be able to help solve some of the diagnostic issues.

Of course, in terms of funding, we are all very worried. But whatever science funding there will be, the photonics world is well positioned. Even so, it's clear that research funding is at risk. Another obvious impact will be in the area of scientific conferences. Zoom has proven to be fantastic—but it's not a replacement.

Most of our generation has not experienced war, but in wars or other hard times, there is a sense of community ... So there is beauty, also, in these situations. OPN

Ph.D. student Omar Florez (right) explains a project to David Garcia, Marianna Sledzinska, and fellow Ph.D. student Francisco Cespedes.

Catalan Institute of Nanoscience and Nanotechnology

REFLECTIONS IN DIVERSITY

Navigating a Career in Research

What does it mean to “make it” as a woman in research? **Clivia M. Sotomayor Torres** shares her thoughts.

Diversity questions surrounding “making it as a researcher” as a non-European woman of color have been unavoidable in the retention and progression steps in my career path. Over the course of my career, I moved several times within the U.K. and Europe searching for the right academic home—a place where I would feel happier in the pursuit of knowledge and mentoring my group.

Reflecting on this path, I have come to the conclusion that a career in research is like a project. It’s long term, requiring planning and prioritization. It has a trajectory—one that will probably include setbacks. And it is subject to unwritten, external factors, such as inequity and comparative advantage, that can affect its progression.

All part of the plan

Why the “project” concept? Because a career path needs to be outlined and prioritized within a person’s “project ecosystem.” Just think of all the steps we take when planning a research or academic project, and apply that more broadly to your career as a whole. Not all steps are successful—the project can bite the dust at the proposal stage. But we get up, rethink, and write another, better one.

In any case, it is crucial to be aware of the external factors, like competition, comparative advantage and timeliness, as well as the internal ones, such as our own degree of ambition and curiosity. Will I be happy with a reasonable academic endeavor, or only if I become a high-flyer?

Is the proposal for my new project so exciting that it will be my top, or almost top, priority for some years?

And what about the "other" factors—the less obvious but significant sociocultural realities? I would argue that they are part of the project planning. Be aware not only of the facts, statistics and trends at your university or institution, but also draw from the experience of senior women in the department or research center about the unwritten factors and their dynamics.

Clivia M. Sotomayor Torres in her lab.

Catalan Institute of Nanoscience and Nanotechnology

Academia's dynamics

As a child with academic parents, I was a great believer in education as a means of social mobility to better society. Now, I am not so sure. Social class, gender and the importance of social contacts are factors that play roles of varying importance in someone's career journey. Their importance may depend on the particular society or region—but they play a determinant role nevertheless, especially in countries with fewer resources for the academic career.

The change from the Humboldtian University model, emphasizing comprehensive, well-rounded learning for its own sake, to the Market University model that prevails today, which focuses on education as a business, has had a huge impact on academia—and, I suspect, a negative impact on women working in the academic sphere. This change turned the academic ethos upside down in terms of values and practices, with concepts like "students as customers," managers instead of self-administration, key performance indicators and metrics. In essence, the transition puts money above the values of knowledge, education and society.

Within the Market University concept, women—who often bring in less money, for a number of reasons—are likely to be disadvantaged at the retention or progression stage of their careers. I wish that I was wrong, but these are facts that should be acknowledged, and their dynamics must be understood at a national, regional, local and institutional level or diversity will suffer. That is why we have professional organizations, trade unions and networks.

I fear that this culture of insufficient consideration to different career paths works against women in research.

I argue that a career in research needs to be seen as the sum of what the person has achieved and has the potential to achieve in the future—a complete picture. However, this requires that institutions value and support different career patterns, based on personal choices prioritizing the various "projects" along the way. To accomplish this, we need to continuously create new tools for recruitment and promotion practices.

Without a coordinated change to the system, I fear that this culture of insufficient consideration to different career paths will continue to work strongly against women in research.

Your own project priorities

Nevertheless, taking all of these factors and hurdles to a research career into account, if one thinks in terms of projects, then success may just be a matter of managing your priorities. "There is a time for everything," we have all heard the saying. Yet there is no avoiding making hard choices at the turning points in our lives.

There is little room for complacency, and little room for serious doubts about the top-priority project while it is running. It needs one's complete attention, as some of the projects are "make or break" at that time and place in one's life. Therefore, I believe that it is advisable to have sorted out your analysis, personal considerations, doubts and reflections in advance.

Yet there is also a place for longer-term reflection. Sometimes, when I think about diversity issues, I become afraid that—having been in a predominantly male environment for more than 40 years—I have subconsciously internalized some of the very same values that hinder diversity. That's a danger for which we all should be vigilant, and on which we should reflect often. OPN

Clivia M. Sotomayor Torres (clivia.sotomayor@icn2.cat), with the Catalan Institute of Nanoscience and Nanotechnology, Spain, is an ERC Advanced Grant recipient.

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LIGHT TOUCH

44 Fewer Shades of Gray

Stephen R. Wilk conducts a historical tour of color theory and the neutral value scale.

ColorChecker
Getty Images

Some time ago, I was looking at a ColorChecker Chart—a handy tool that is widely used to check on the response of cameras, films, and, increasingly, camera systems to a standardized series of colors. The rectangular chart comprises 24 colored squares arranged in four rows of six.

The third row down contains the three additive and the three subtractive primary colors—undoubtedly the source of the six-column arrangement. The two upper rows feature a selection of hues intended to be representative of commonly photographed subjects—dark and light skin, blue sky, green plants, and so on. The bottom, monochromatic row contains six squares of varying shades of gray, ranging from completely white to completely black. This was the line that piqued my interest.

If I were putting together such a chart, my first impulse would be to have the grays advance in regular steps of reflectivity—0%, 20%, 40%, 60%, 80% and 100% reflecting. Which shows how naïve I am. The actual reflectivities, as set down in the 1976 *Journal of Applied*

Photographic Engineering paper by McCamy et al. proposing the chart, are 3.1%, 9.0%, 19.8%, 36.2%, 59.1% and 90.0%. The steps are neither obvious nor uniform in size.

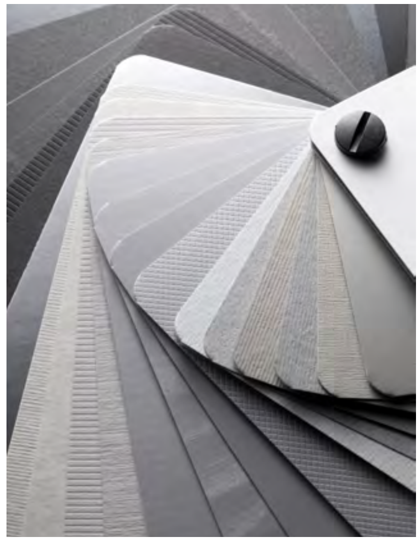
Well, if the steps aren't equally spaced in reflectivity, then surely they are uniform in optical density, right? Again, no. The corresponding densities are 0.046, 0.228, 0.441, 0.703, 1.046 and 1.509.

Grading grays

The truth, as readers in the photographic and color sciences already know, is that the steps are chosen on a different basis. As McCamy et al. explicitly state, "The series is equally spaced on the Munsell system." And indeed, using the Munsell color system, all of the squares in the bottom row have zero "chroma," but differ by steps of 1.5 in "value": 9.5, 8, 6.5, 5, 3.5 and 2.

But this simply shifts the question one step further back—McCamy et al. may have lifted the equally stepped gray squares from the Munsell color pack, but where did Munsell get those values from? The answer lies in human perception.

Each step in the Munsell "value" designation is meant to represent symmetrical steps of gray as we perceive them—the result of the interaction between the (standardized) light source, the pigmented color squares, the human eye and the color-processing machinery of the human brain. Since the human visual system is part of the process, this is the ultimate in subjective evaluations. Nevertheless, although people's perceptions are notoriously variable, people are, statistically, pretty much the same—and in statistics lies our salvation. Amassing the results from a large number of subjects, we expect these human differences to average out.



Getty Images

Each step in the Munsell "value" designation is meant to represent symmetrical steps of gray as we perceive them.

Again, were I to set up a procedure for determining the reflectivities of six equally spaced shades of gray, as perceived by the average human being, my thought would be to generate a large number of gray test squares of known reflectivity, and to get a sizable group of volunteers (say, about 100) to select what they thought were six equally spaced shades of gray.

It probably won't surprise you to learn that this is not the route Munsell took at all. A long history shaped the experimental process that helped to determine human perception of various levels of gray.

A tale of two laws

Our story begins in the 18th century with Pierre Bouguet, a French professor of hydrography, who was fascinated by the human eye's ability to perceive variation in light intensity. Specifically, he wanted to know what was the "just-noticeable difference" detectable by the eye. His result, published in 1780, stated that the just-noticeable difference was proportional to the brightness of the source, and that in the case of his own eye, the difference in brightness was 1.5%.

This general rule, since confirmed by many scientists studying human vision, is now called the Weber-Fechner law—after the German physician Ernst Heinrich Weber and his student Gustav Theodor Fechner, who formulated it as a general principle. The Weber-Fechner Law can be boiled down to the simple form $V = c \log R + k$, where V is the sensation, R is a measure of the stimulus (typically reflectance in visual studies), and c and k are constants. This simple law, however, soon found complications—it appeared that the fraction corresponding to the just-noticeable difference, often called the Fechner Fraction, wasn't really a constant, but varied slowly with intensity.

The Belgian physicist Joseph Antoine Ferdinand Plateau suggested a different relationship, now known as Plateau's Law: $V = kR^c$ —where V and R have the same definitions as above, and k and c are again constants (although completely different ones). There were thus, by the end of the 19th century, two different equations relating sensation V to stimulus R, one logarithmic and the other exponential. Clearly both could not be correct. It turns out, in fact, that neither properly accounts for the relationship between the reflectance of light and the human response across all circumstances.

Munsell "steps" in

When painter and color theorist Albert Henry Munsell started

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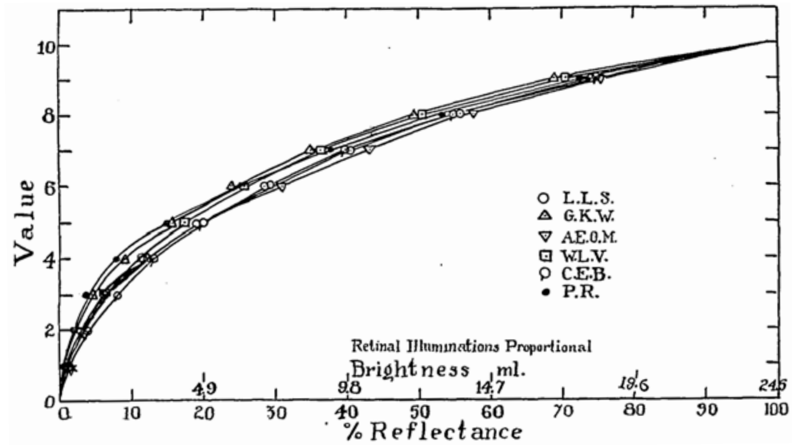


The Munsell Company plot of value versus signal (reflectance) for six observers.
A.E.O Munsell et al., J. Opt. Soc. Am. **23,** 394 (1933)

developing his notation for colors around 1900, he looked for a reliable system and could find no consensus. He provisionally adopted Plateau's law, invented his own photometer for his experiments, and continued to make measurements clarifying this (and other aspects of his color scheme) until he died in 1918. He established the Munsell Color Company in 1917 to work out and market his ideas on standardized colors, and after his death, the company was run by his son, Alexander Ector Orr Munsell.

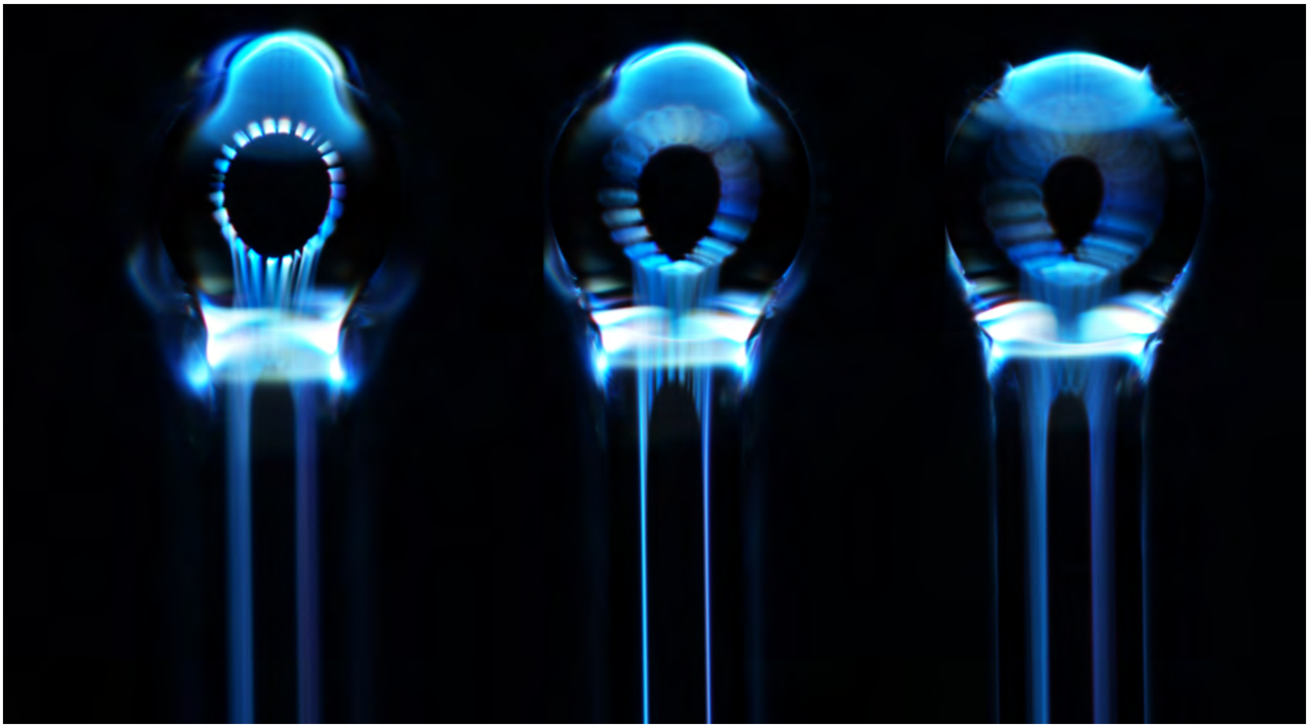
In 1933, the younger Munsell and his team published their findings on "neutral value scales" in the *Journal of the Optical Society of America*—producing an experimental curve showing the average relationship between the reflectance of the target and the "value" of the gray as perceived by the subject. In some cases, it could be stated as an integral number of just-noticeable differences. The exact shape of the plot has the general form of a fractional power law, as the Plateau model might suggest, but it does not quite fit a simple square root or cube root formula. Over the years, a variety of formulas have been implemented, generally in the form of a fractional power law with one or more correction terms.

Using any of the formulas, or interpolating between averaged experimental points, allows one to give a series of grays separated by steps of equal sensation. Munsell et al. give a series of reflectances to create a scale of ten steps, but you can construct a system for any number of steps once you have a curve relating reflectance to response.

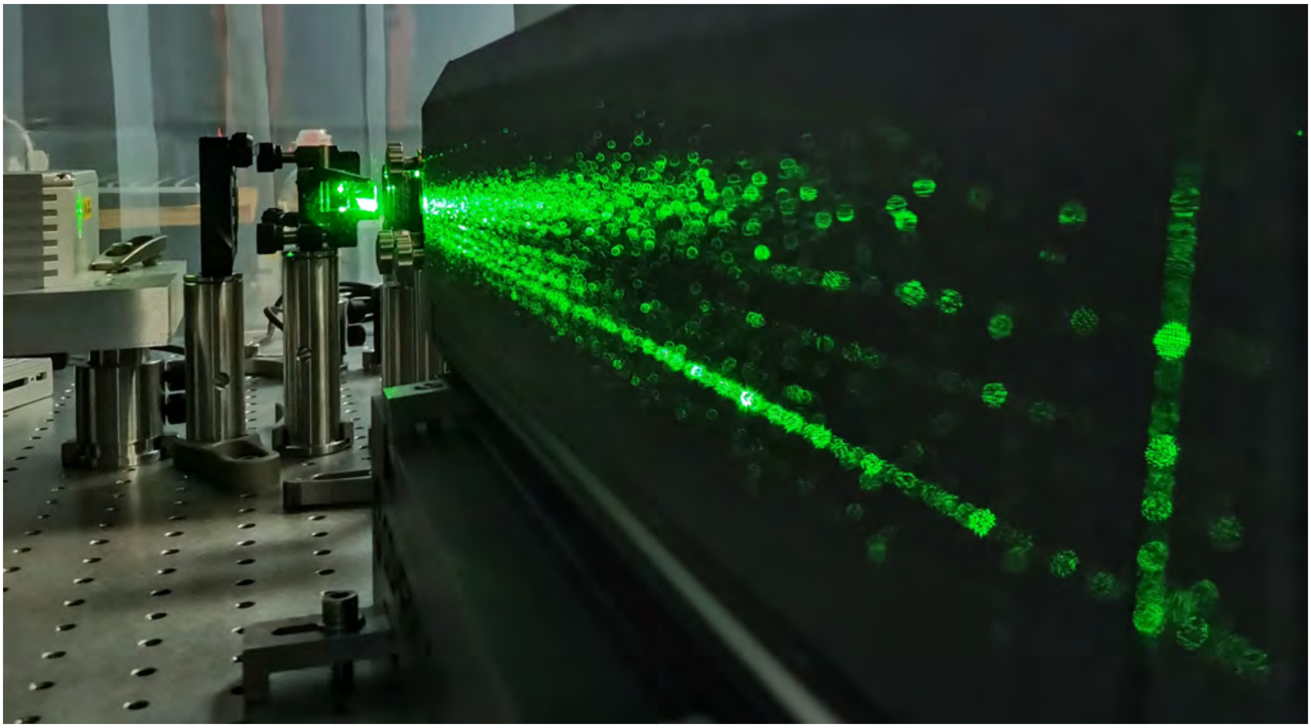
So, at last, we can answer the question of how the steps of equal stimulus were devised. The Munsell Company did indeed use a battery of observers in a controlled viewing booth, as was my initial thought; however they used a maximum of 16 subjects for one test—far below my suggested 100 subjects. Of course, repeated testing by multiple researchers on varying numbers of subjects confirmed the general shape of the curve, even if no one test featured more than 16 subjects, so the overall number of measurements confirming the curve is much higher. Most papers since the 1940s take the form for granted, and produce their modifications of the formulas from earlier data. OPN

Stephen R. Wilk (swilk@comcast.net) is with Xenon Corp., Wilmington, MA, USA.

Member Lens *Cool optics images from our readers*



Dark-field microscope images of silica microspheres (~250 µm diameter) fabricated on the tip of an optical fiber.
—Kamila Tieppo, Mackenzie Presbyterian University, São Paulo, Brazil



A continuous laser beam, reflected by a broken cube beam splitter, is scattered on the side of another laser.
—Félix E. Torres, Instituto de Física, UNAM, Mexico

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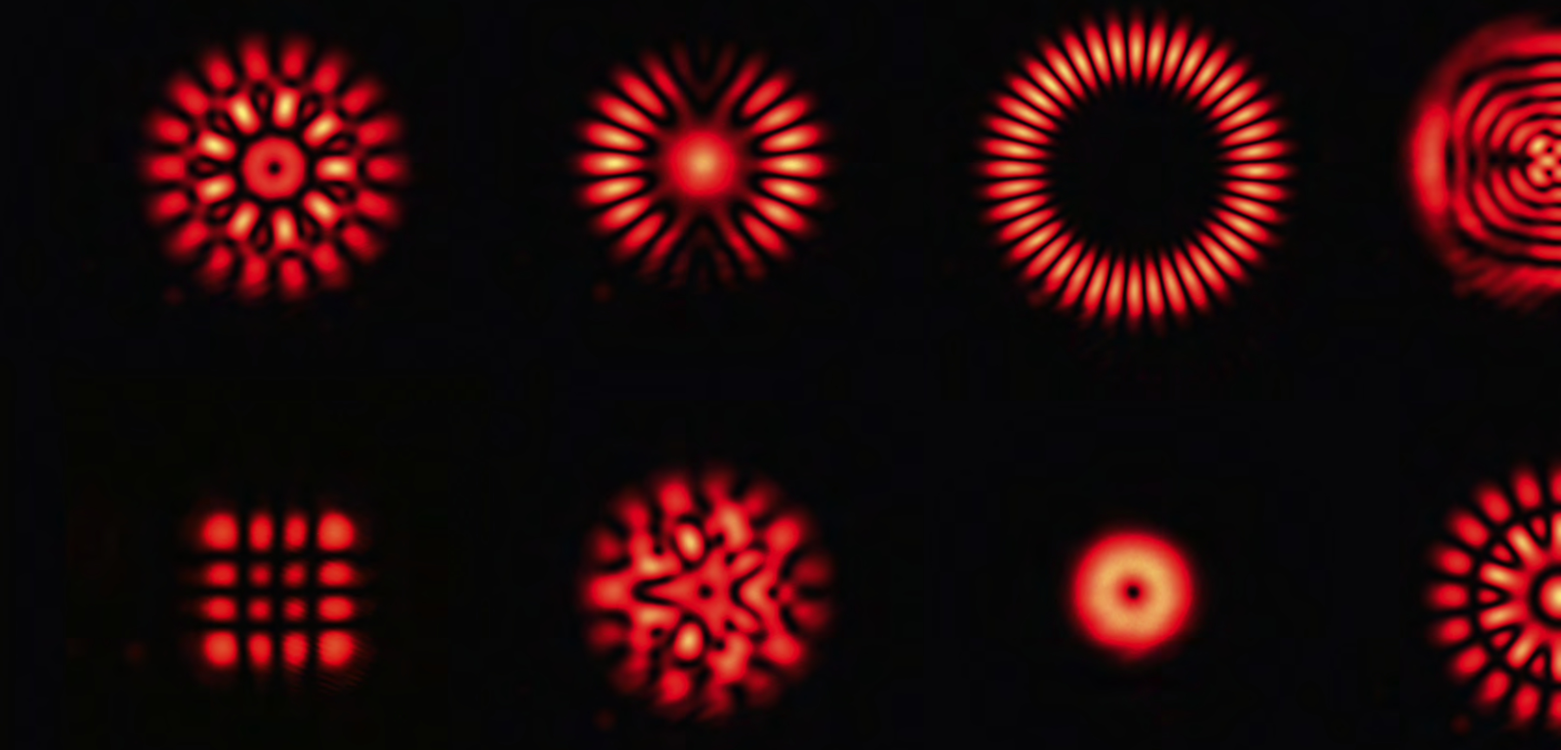
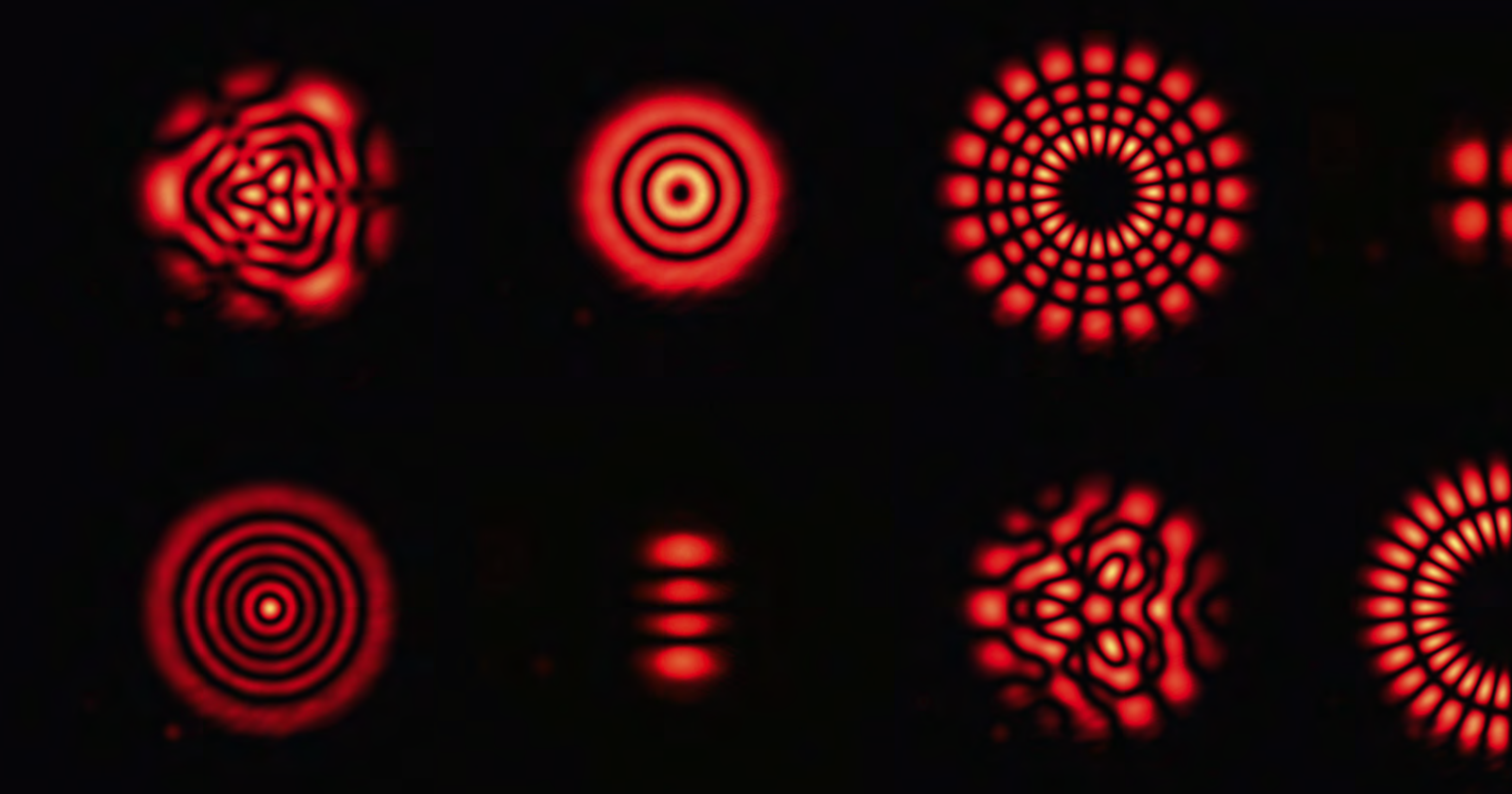
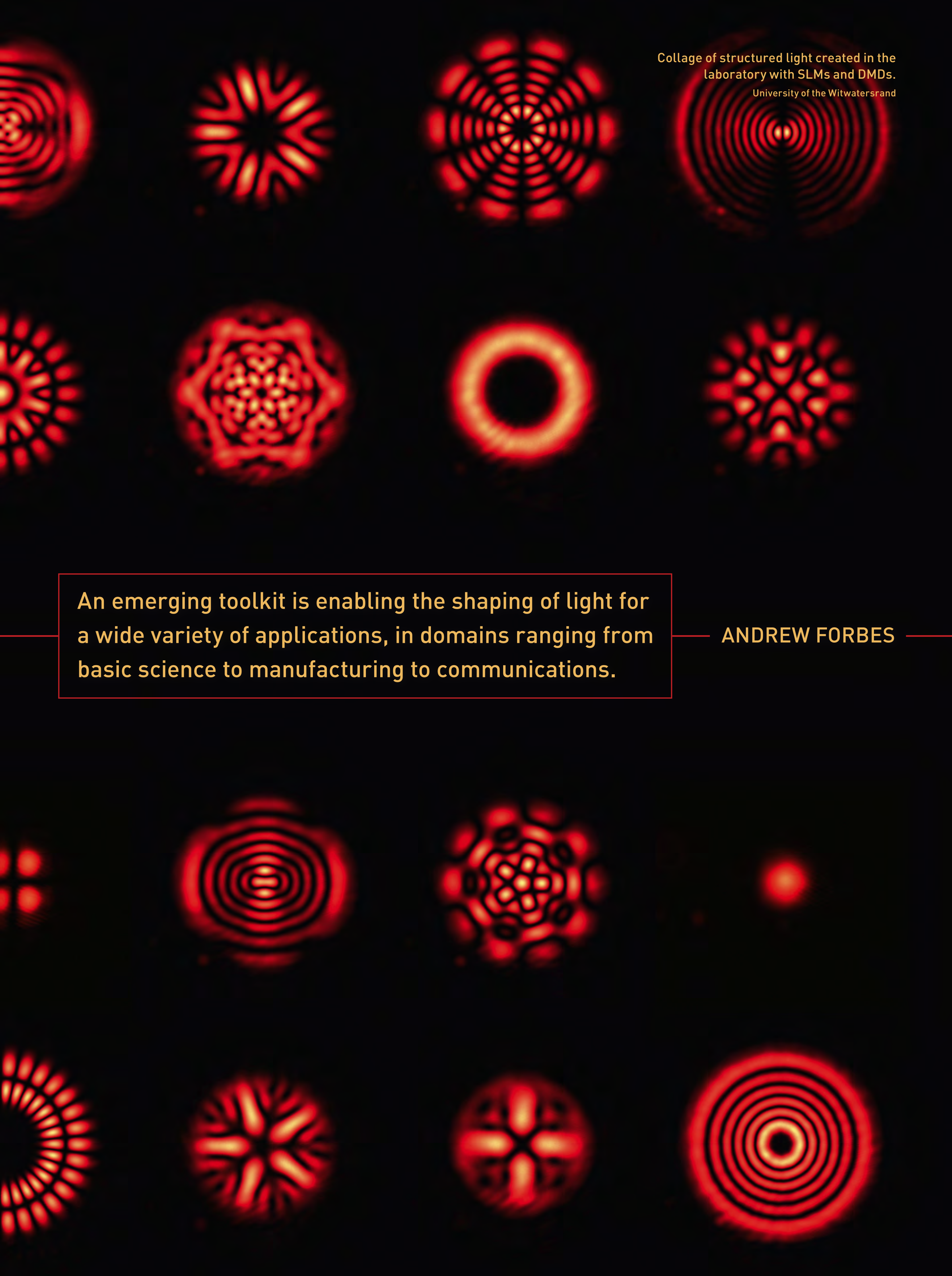


STRUCTURED LIGHT

Tailored for Purpose

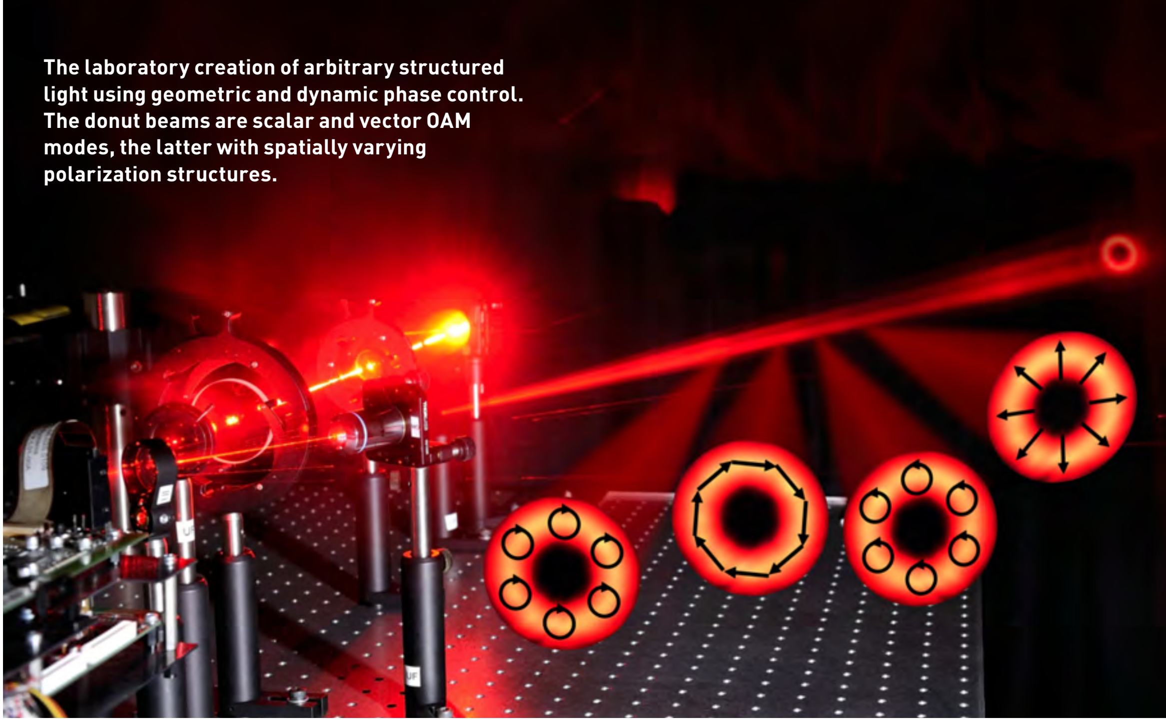




Collage of structured light created in the laboratory with SLMs and DMDs.
University of the Witwatersrand

An emerging toolkit is enabling the shaping of light for a wide variety of applications, in domains ranging from basic science to manufacturing to communications.

ANDREW FORBES



The laboratory creation of arbitrary structured light using geometric and dynamic phase control. The donut beams are scalar and vector OAM modes, the latter with spatially varying polarization structures.

University of the Witwatersrand

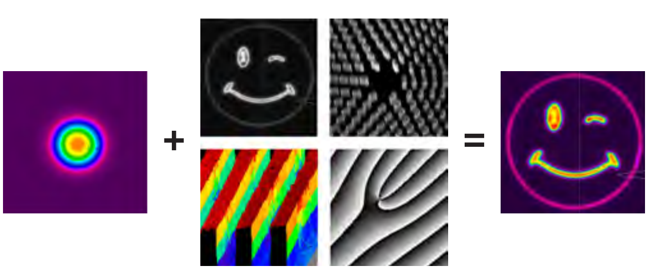
Structured light refers to the tailoring or shaping of light in all its degrees of freedom—whether in time and frequency, to create ultrafast tailored time pulses; or, more commonly, in controlling light's spatial degrees of freedom such as polarization, amplitude and phase. Although the term "structured light" was coined only about a decade ago, the notion of controlling light has a very long history. The first recorded account of tailoring light is the probably apocryphal tale, during the siege of Syracuse (circa 213–211 B.C.E.), of using multiple mirrors to shape the intensity of sunlight on Roman ships, setting them on fire—an example of multi-faceted incoherent beam shaping. Lenses and imaging systems likewise may be considered early forms of tailoring light.

It was the advent of the laser, however, that ushered in true control for structuring light. Better known as laser beam shaping (see "Laser beam shaping," OPN, April 2003), the field took off in the late 1980s and early 1990s, driven by the interplay of optics and computing. Better optical techniques led to advances in lithography for smaller microelectronics, fueling faster computers; the improvement in computing power and lithographic techniques, in turn, allowed calculation and fabrication of new optical designs.

From DOEs to DMDs

This interplay saw the emergence of computer-generated holograms (CGHs), implemented as diffractive optical elements (DOEs). Previous Fourier "tricks" for advanced pattern recognition could now be generalized

CONTROLLING AMPLITUDE & PHASE



1. STRUCTURING LIGHT

Commonly, structuring light involves converting an initial beam (such as the Gaussian at left) into a desired structure (such as the intensity structure at right). The intermediate steps can exploit amplitude or phase control (or both), via variable transmission filters, metasurfaces, diffractive optics, holograms and other tools.

2. AMPLITUDE CONTROL

Variable loss in different beam regions

DYNAMIC PHASE CONTROL

Optical path length difference, through surface-profile or refractive-index changes

GEOMETRIC PHASE CONTROL

Anisotropic media introduce an extra, polarization-dependent phase delay that can be exploited

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Structured light refers to the tailoring or shaping of light in all its degrees of freedom.

and implemented as high-performance, phase-only elements for arbitrary light control. Despite the potential, the uptake was mostly limited to shaping light intensity—for example, Gaussian-to-flat-top intensity converters for various industrial applications. The high fabrication cost of one-off elements, often running into tens of thousands of U.S. dollars, was a major hurdle. Meanwhile, free-form and aspheric technologies had not reached the versatility they enjoy today, so the cheaper option of refractive solutions was very limited.

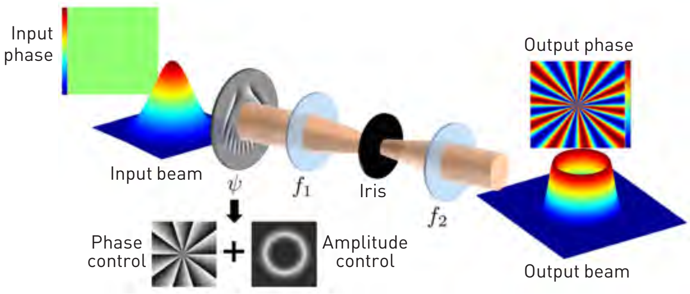
The structured-light field advanced slowly until the development of commercial rewritable spatial light modulators (SLMs) for photonic applications. The foundations of today's liquid-crystal-on-silicon (LCoS) SLMs were laid in the 1970s at Hughes Aircraft Corporation (following on the heels of the laser), but these only moved out of traditional projector markets and into photonic structured-light devices in the early to mid-2000s. This readily available, rewritable implementation technology fueled an explosion in structured-light research. Digital micromirror devices (DMDs)—which offer increased speed and reduced cost, at the expense of efficiency—promise a similar advance today.

All of these approaches and tools control the amplitude and dynamic phase of light. Another important component in any structured-light arsenal, however, is the exploitation of geometric phase, possible through liquid-crystal holograms and metasurfaces (see "Controlling light with geometric-phase holograms," OPN, February 2016). Once again, computing power coupled with advances in fabrication technology is helping to reshape opportunities in photonics, affording the ability to easily tailor light's polarization structure beyond spatially homogeneous states. That, combined with control of amplitude and dynamic phase, has allowed the easy creation of arbitrary forms of structured light—in many cases using commercial, off-the-shelf devices.

Amplitude, phase and polarization

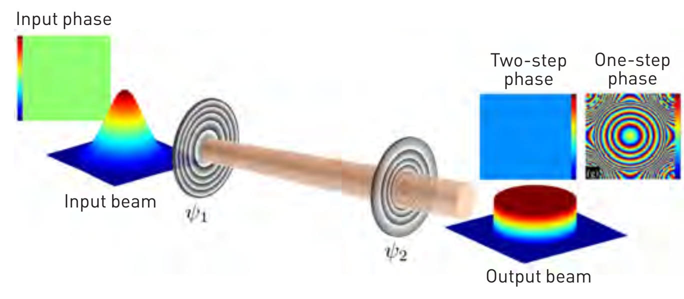
We would like a toolkit that makes it possible to take an initial optical field and reshape it to another in amplitude, phase and polarization. A variety of approaches exist to achieve amplitude and phase control of homogeneously polarized scalar beams (see "Controlling amplitude and phase," below). Creating exotic polarization structures requires amplitude and phase control of each polarization vector in the optical field—of how the right-circularly and left-circularly polarized or linearly polarized components of the light appear. The sum of two components with differing spatial properties gives rise to vector states of light with spatially inhomogeneous polarization structures. For example, if the two circular polarization states have azimuthal phases of opposite helicity, the resulting beam will be a cylindrically symmetric vector structure: one example would be radially polarized light with linear polarization vectors that point radially everywhere.

Since structured vector beams are just the sum of two structured scalar beams, the traditional toolkit for



3. LOSSY LIGHT SHAPING

Using amplitude and phase control in a single step creates the desired beam (such as a vortex OAM beam from a Gaussian input), but always with an energy loss. Here, the vortex phase excites many radial modes, which can be suppressed only by amplitude control.



4. LOSSLESS LIGHT SHAPING

Lossless light shaping can be done in two steps (e.g., a Gaussian beam converted into a flat-top beam with a flat phase), or in one step if a degree of freedom can be ignored (e.g., a Gaussian beam converted into a flat-top beam with unspecified phase).

Custom intracavity optical elements and geometries allows for structured light at the source. Here, an illustrative cavity with internal metasurfaces is shown to output twisted OAM modes.

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scalar beams can be applied separately and then added interferometrically. This exploits dynamic phase only. Geometric phase can also be exploited—via subwavelength structures on metasurfaces, or via large-scale structures in liquid crystals—to induce a phase change that differs for each polarization, so that the vector beam is created directly. Interestingly, in the early days of small-feature-size DOEs, vector effects were known but usually considered unwanted artifacts; today these effects offer full control of structured light.

Structured light from lasers

Structured light can also be created directly at the source, in so-called structured-light lasers. Researchers creating structured light from cavities in the early lasers used intracavity wires, stops and apertures to produce Hermite-Gaussian and Laguerre-Gaussian beams. Often intracavity approaches are used to "unstructure" light—for example, using a simple circular aperture to produce only a Gaussian mode and not many transverse modes, or using adaptive optics to remove phase structured from thermal aberrations. Gain control rather than loss control can also be used to create structured light from lasers—for instance, by dynamically shaping, with a DMD, the light field that pumps the laser.

Intracavity phase elements have been extensively used since the 1990s to produce exotic states of light from lasers. Such schemes work by defining a desired intensity and phase at the output of the laser and reverse-propagating it to the back mirror. If the mirror acts as a phase-conjugating element, then the desired beam will emerge again at the output. Since this process repeats after each round trip, the specified mode is an eigenmode of the cavity.

A structured-light form of particular popular interest is light carrying orbital angular momentum (OAM)—"donut"-looking beams characterized by an azimuthally twisted phase profile and a central intensity null (see "Light served with a twist," OPN, June 2017). Creating OAM modes directly from a laser is not an easy task, as nature cannot tell the difference between a clockwise and anticlockwise twisted mode: they have the same propagation dynamics, the same beam sizes, the same wavefront curvature and so on, making them hard to distinguish in a laser. Paradoxically, creating such beautifully symmetric modes usually requires some form of symmetry breaking. One such approach is to use geometric phase, via exotically structured matter, to produce novel states of structured light.

A menu of structured light

The toolkit outlined above has enabled creation of many forms of structured light. These include well-known eigenmodes of free-space in the form of Hermite-Gaussian (HG), Laguerre-Gaussian (LG) and more general Ince-Gaussian (IG) beams, as well as eigenmodes of many optical-fiber systems, including lineraly polarized (LP) and cylindrical vector vortex (CVV) modes.

Considering only specific aspects of the light field, rather than its totality, lets one engineer light that bends the rules of physics. One example is "nondiffracting" Bessel beams, which appear to propagate without spreading—but only if the central region of the beam is considered. Another is the famous Airy beam, which seems to accelerate transversely and propagate on a curved trajectory—but only if the main lobe alone is considered; the entire beam follows a straight-line path at a constant speed.

General forms of structured light have since been shown, including radial and angular accelerating optical beams, photonic hooks, caustic beams, elegant LG and HG beams, and exotic polarization singularity structures that include so-called lemon, star, monstar, spider, web and flower states. OAM states of light show twisted helical phase structures, like a spiral staircase; the twist can be clockwise or anticlockwise, and twisted once, twice, three times or more per wavelength—resulting in a phase singularity at the beam center and a zero-intensity region that increases with the amount of twist.

The creation of these 2D transverse states can be generalized to arbitrary 3D structured light in some region of space, usually about some focal point. Examples of this include the creation of polarization Mobius-strip beams, knotted singularities in phase and polarization, The notion of quantum states of structured light offers a particularly intriguing angle on detection—quantum detection plays a role analogous to classical creation.

Talbot array beams and fractal states of light. Sometimes it is beneficial to keep one dimension small, as is the case of light sheets for microscopy, or to make the 2D structure change during propagation for 3D light.

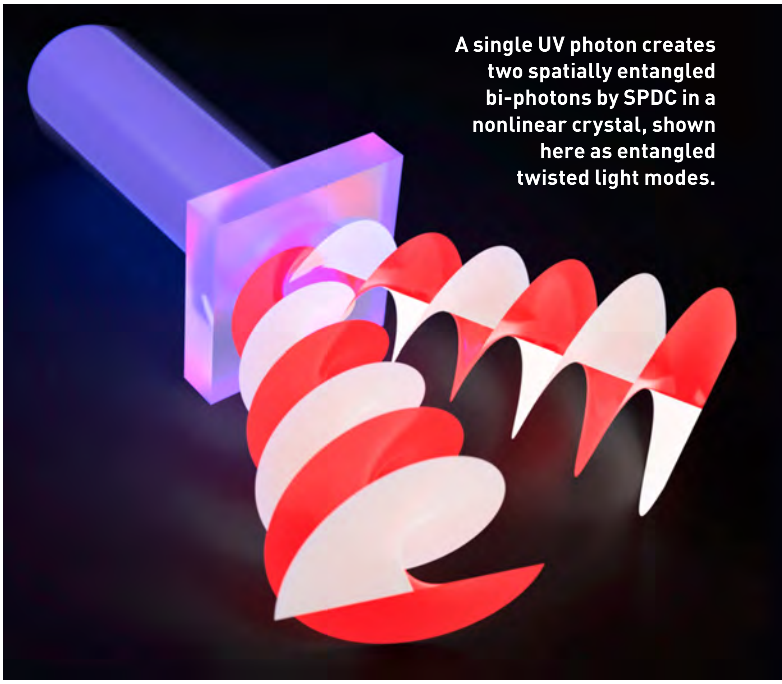
Recently 2D light has been modulated at many planes by multiple 2D phase modifications, evolving simple structured light into more exotic multimodal forms, useful for both creation and detection in the context of optical communication, and even as high-dimensional quantum gates. Still another emerging field is the 4D control of light—spatial and temporal control—which remains largely unexplored.

Detecting structured light

Having created structured light, we also want to detect it. In most cases, light's reciprocity allows the detection step to be the creation step run backwards. Unraveling the phase, amplitude and polarization recovers the initial beam—often a Gaussian. A simple single-pixel detector or coupling to a single-mode fiber allows quantitative analysis of the field by modal decomposition. These approaches—essentially nothing more than the match-filter technology from early optical pattern recognition—can be made more efficient by sorting various modes deterministically using two-step lossless conformal mapping. Such mode sorters have been developed and applied to LG, HG and Bessel beams (see "Unraveling Bessel beams," OPN, June 2013).

The notion of quantum states of structured light offers a particularly intriguing angle on detection—quantum detection plays a role analogous to classical creation. In a vanilla version of a quantum experiment with structured light, a Gaussian pump excites a spontaneous parametric down-conversion (SPDC) process in a nonlinear crystal to produce two photons entangled in their spatial mode. But the state is not defined until it is measured: the entanglement could be expressed in any spatial mode, so one cannot speak of the two photons as "being" HG, LG or Bessel modes. The post-selection of one pattern versus another collapses the state into the one that's measured.

Because many spatial mode sets are orthogonal and complete, they form a natural way to express the entanglement. Simply put, this is quantum mechanics with patterns of light, and it works because the patterns can be unique. The hope is to exploit the infinite number of patterns to access infinitely large Hilbert spaces—both for asking fundamental questions of quantum mechanics, and for exploiting entanglement as a resource.



A single UV photon creates two spatially entangled bi-photons by SPDC in a nonlinear crystal, shown here as entangled twisted light modes.

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Light tailored to fit

Given the versatility in control of structured light fields, it is not surprising that they have found many applications across multiple disciplines.

Optical trapping and tweezing. Because trapping relies on the gradient force—proportional to the gradient of the intensity—tailoring light opens new possibilities. Beyond the ubiquitous Gaussian mode, traps have been designed using OAM modes to form optical "spanners" that rotate matter at ultrafast speeds; Airy beams for optically mediated particle clearing; Bessel beams to trap particles at multiple planes, optically sort blood cells and form optical conveyer belts as counter-propagating light fields—to name but a few. Structured light has been instrumental in controlling matter and flow in

STRUCTURED LIGHT: SOME APPLICATIONS

OPTICAL TRAPPING/TWEEZING

Polarization nano-tomography of tightly focused light landscapes by self-assembled monolayers.

Courtesy of Eileen Otte, University of Münster

MATERIALS PROCESSING

Cutting of ultrathin (<50 μm) and thick (>10 mm) glasses using ultrashort pulsed lasers and non-diffracting beams. The self-reconstructing beam enables high-quality separation of transparent materials by controlling crack orientation during the formation of a breaking layer.

Courtesy of Daniel Flamm, Trumpf

COMMUNICATIONS

The spatial degree of freedom holds tremendous promise for increasing present optical bandwidth: new information channels could be created by encoded information into the patterns of light.

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microfluidic systems, and the interaction of structured light and structured matter is essential for control at the nanoscale through near-field effects.

Super-resolution microscopy. Stimulated-emission depletion (STED) microscopy, one of the technologies recognized by the 2014 Nobel Prize in chemistry, is enabled by use of two forms of pulsed structured light. A first (usually Gaussian) pulse excites fluorophores inside the illuminated region, and a second (usually hollow) pulse returns the fluorophores within the ring-shaped area to the ground state via stimulated emission. Thus only molecules within the center of the STED beam will fluoresce, allowing the point-spread function to narrow and increasing resolution beyond the diffraction limit. STED microscopy has achieved up to 20 nm lateral resolution and up to 40 nm axial resolution.

It's hoped that structured light can continue to address challenges in microscopy—poor contrast in unstained biological samples, limited spatio-temporal resolution, the difficulty of looking deep into light-scattering samples—in both the illumination and detection stages. Here the form of the light is paramount: light sheets for selective plane imaging; iterative beam shaping to optimally structure light to see deeper into scattering tissue; LG beams as the hollow beam for STED.

Manufacturing. Laser-enabled manufacturing has long used structured light to increase processing speed and quality and to optimize cost and efficiency. Tailoring the intensity profile has led to efficient drilling—for example, VIA drilling for microelectronics with flat-top beams—while polarization control has been essential for cutting along arbitrary geometries. For metal cutting with a large ratio of sheet thickness to width, radially polarized light offers a cutting efficiency twice as large as with linearly polarized beams.

Vector beams have also come to the fore because of their efficacy in removing waste material from the interaction zone, and the ability to focus tightly with strong longitudinal field components. In fact, tuning transverse and longitudinal field components enables arbitrary shaping of the focal spot, facilitating flat-top intensity profiles at the focus without traditional beam shapers. Nondiffracting beams have recently improved the cutting of thin and thick glasses and etching of 2D contours.

Communications bandwidth and security. The idea of using spatial modes of light as a new degree of freedom in optical communications dates back to the

It has never been easier to get started with structuring of light—and, pertinently, everyone is working with some form of structured light, even if not by design.

early 1980s but has gained traction in the past decade, based on both increasing need and a readily available toolkit. Ideally, each pattern would act as a new channel carrying the maximum information capacity possible with present technologies, with N patterns translating to an N-fold bandwidth gain. In reality, coupling between spatial modes in optical fiber and turbulent free-space limits the channel capacity, while digital signal processing correction becomes prohibitive for large, multi-channel systems.

Nevertheless, faster communication with structured light has exceeded terabit-per-second speeds, with ever-increasing distances demonstrated using custom-designed fiber. After a seminal demonstration down the corridors of the University of Glasgow, U.K., around 15 years ago, OAM has been the mode of choice, but studies have shown the potential benefit of other modes—for example, Bessel beams for self-healing links, HG beams for resilience to tip and tilt, and combinations of mode types that experience channels differently to leverage diversity, the other side of the mode-division-multiplexing coin.

Meanwhile, structured light at the quantum level could hold the key to improved data security. Many patterns offer access to a high-dimensional quantum state, known to allow higher information capacity per photon and a higher tolerance level to noise—both vital for quantum key distribution (QKD). The first QKD with structured light was performed with OAM and its mutually unbiased bases, followed by QKD and entanglement preservation through obstacles with Bessel states, and long-range free-space (up to around 300 m) and fiber (up to around 1 km) quantum links with hybrid entangled modes in polarization and OAM. While the quantum toolkit for structured light is still far behind that for polarization, the potential benefits are driving rapid progress in the field.

Open challenges and opportunities

Various national photonics strategies have labeled this the century of the photon, with the promise of photonics replacing much of electronics. Yet despite centuries of effort, we do not have the same control in photonic systems as we have in electronic systems. The toolkit for controlling structured light, while substantially enriched in recent years, is still mostly empty: we have few options for compact sources of structured light, few easily available solutions that are not custom-made, and few that work at higher power levels and/or fast switching rates. At present, to deploy a structured-light solution, the user must be a structured-light expert. That's akin to asking all microscope users to first design their own objectives!

Yet it has never been easier to get started with structuring of light—and, pertinently, everyone is working with some form of structured light, even if not by design. Rather than use the light from your laser as it comes, why not tailor it for your particular application? This is the opportunity: structured light, tailored for purpose. OPN

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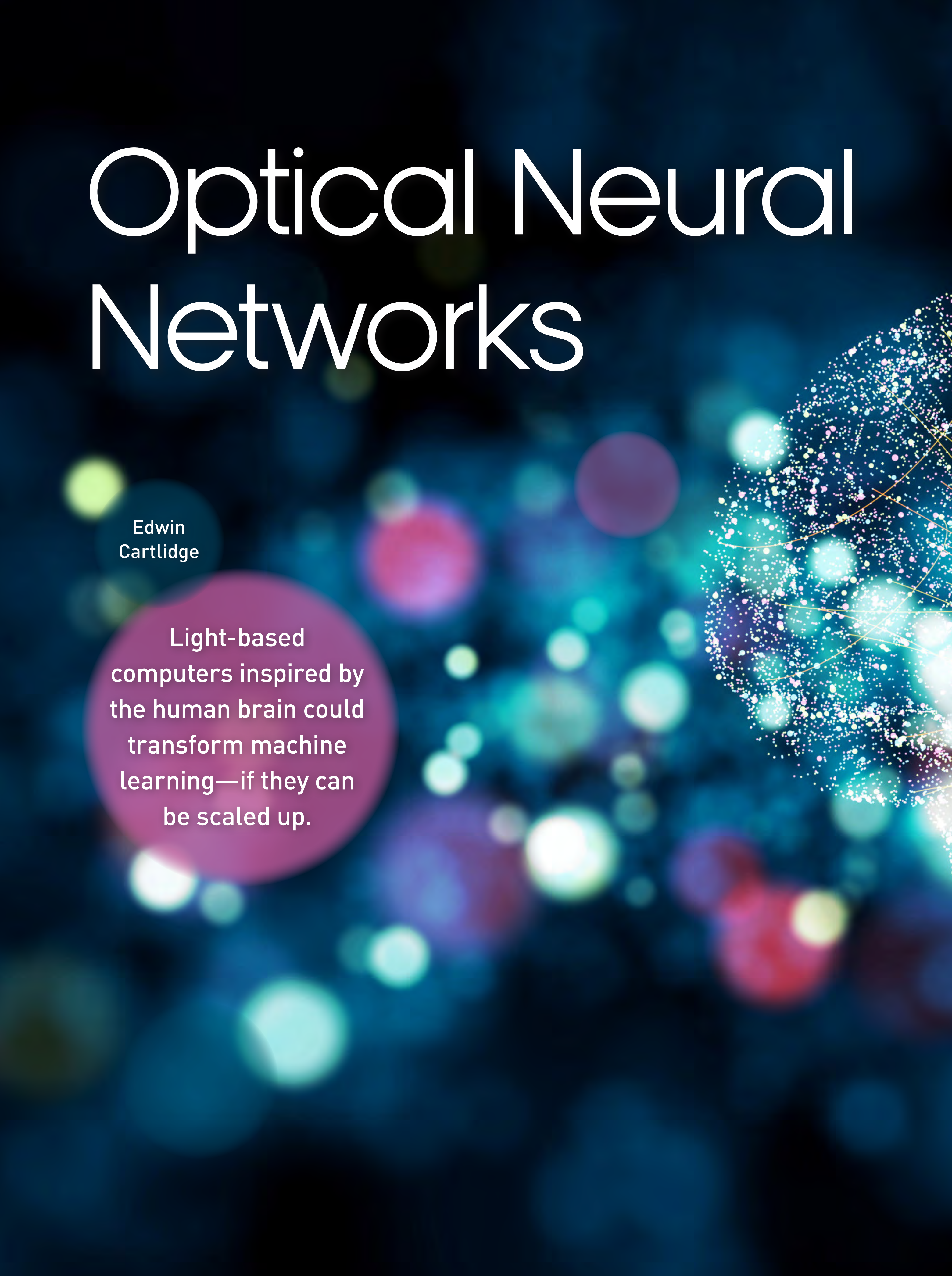

Optical Neural Networks

Edwin Cartlidge

Light-based computers inspired by the human brain could transform machine learning—if they can be scaled up.

Getty Images

Google has developed a neural-network chip to help keep AI applications from overwhelming its data centers—but the chip is still digital.

Google

Recognizing faces in photos, monitoring credit-card transactions for fraud, recommending music based on personal taste and identifying tumors in medical images—artificial intelligence has made huge strides in recent years. These advances and many others have come about largely thanks to progress in neural-network computing and "deep learning."

Somewhat akin to how the human brain works, these networks tune the connections between large numbers of artificial neurons to spot patterns in data sets. Though first developed in the 1950s, artificial neural networks (ANNs) have really taken off only in the last decade or so, according to Jeffrey Shainline of the U.S. National Institute of Standards and Technology (NIST) in Boulder, CO, USA. He attributes that growth to improved training algorithms, more powerful computers and a flood of internet data.

Nevertheless, their many internal connections and need for extensive training can make ANNs very demanding computationally. Several years ago, for example, Google realized that its ever-growing use of AI could lead to a huge increase in energy consumption at its data centers. In response it created a new "Tensor Processing Unit" that saves energy by foregoing universal programmability and focusing instead on the matrix operations that lie at the heart of ANNs.

As powerful as the chip might be, however, it is still based on the basic architecture developed in the 1940s by John von Neumann. That architecture involves wires ferrying data and instructions back and forth between memory and processor—a precise but step-by-step process. In contrast, ANNs, like biological brains, are decentralized and inherently parallel. Thus, when run on digital computers, they have to be simulated using software (even in the case of IBM's TrueNorth chips, which process data within distributed memory units).

Analog optical technology instead allows ANNs to be implemented directly in hardware, with data encoded in pulses of light and neurons made from beam splitters, waveguides and other components. Freed from the constraints of a clock cycle, argues Junwei Liu, a physicist at the Hong Kong University of Science and Technology, these circuits can potentially be much quicker and more energy-efficient than existing networks. As he explains, their processing time is set not by the number of neural links but simply by how long it takes light to traverse the circuit. "And light," Liu points out, "is very fast."

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Optical technology allows ANNs to be implemented directly in hardware, with data encoded in light pulses and neurons made from beam splitters, waveguides and other components.

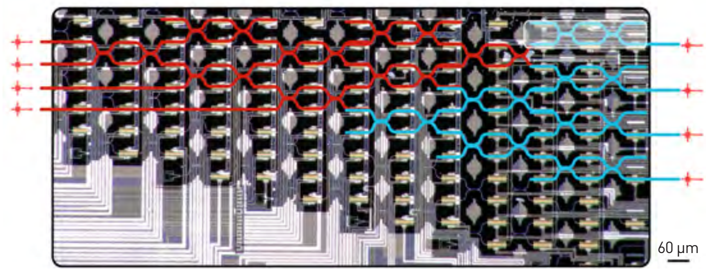
Coherent solutions

Following the laser's invention in 1960, scientists started to dream of building an optical computer. The emphasis initially was on a digital device, which would use the optical equivalent of a transistor to switch beams of light on and off. Such a machine, claimed its proponents, might operate much faster than an electronic computer, thanks both to the far higher raw speed of light through a circuit and to the possibilities for parallel processing, since photons don't interact with one another.

However, this very non-interaction of photons itself created a problem, as it means that they couldn't be used directly to control the behavior of other photons. Instead, switching had to be done indirectly, by modifying some kind of intermediate material. But the power needed to achieve such nonlinearity was so high that many proposed optical schemes were impractical for more than a handful of logic gates. Unable to build an optical transistor that could come close to outperforming its electronic equivalent, many researchers left the field in the 1970s.

Yet these problems didn't spell the end of optical computing. As Alexander Tait at NIST in Boulder explains, optical ANNs have less need for switching than digital computers. In an ANN, each neuron receives multiple weighted (linear) inputs, but generates just one (nonlinear) output (see "The power of learning," p. 36). So whereas a gate-based circuit contains large numbers of nonlinear elements (an AND gate, for example, consists of two transistors in series), the nonlinearity in an ANN is restricted to neurons' output. And that remains true, Tait points out, no matter how many connections there are to a given neuron.

Physicists have devised numerous ways of realizing ANNs optically, one of which uses Mach-Zehnder interferometers (MZIs) to calculate matrix products. By interfering a coherent pair of incoming light pulses having introduced a specific phase shift between them, these devices multiply a two-element vector, encoded in the amplitude of the pulses, by a 2×2 matrix. An array of the interferometers can then perform arbitrary matrix operations.



Researchers at MIT have used a photonic processor containing Mach-Zehnder interferometers to carry out matrix multiplication, consisting of unitary transformations (red) and attenuation (blue).

Reprinted with permission from Y. Shen et al., Nat. Photon. **11**, 441 (2017)

These operations were first carried out using meter-length bulk optics, but advances in integrated photonics have shrunken things considerably. In 2015, groups at the University of Bristol, U.K., and the Massachusetts Institute of Technology (MIT), USA, announced independently that they had made "nanophotonic processors" capable of carrying out general matrix operations that could potentially be applied to a variety of problems in classical and quantum physics.

The MIT groups, led by Dirk Englund and Marin Soljačić, went on to use 56 MZIs from part of their nanophotonic processor to implement two layers of four neurons. Encoding four different vowel sounds spoken by 90 different people in laser pulses, and using half the data for training, they found that the network identified the sounds correctly 77% of the time, compared with 92% using a conventional 64-bit digital computer.

Despite these positive results, the scheme faces major challenges. For one thing, says Tait, scaling up to larger numbers of MZIs will be difficult, partly because the phase shifters require lots of power. Then there is the question of the nonlinear operation needed to link one set of MZIs with another, which the MIT researchers simply simulated using a normal computer. According to Tait, this nonlinearity would corrupt the light's phase, ruining the calculations. Adherents of this technology, he says, "have yet to propose how the MZIs will cascade from one to another."

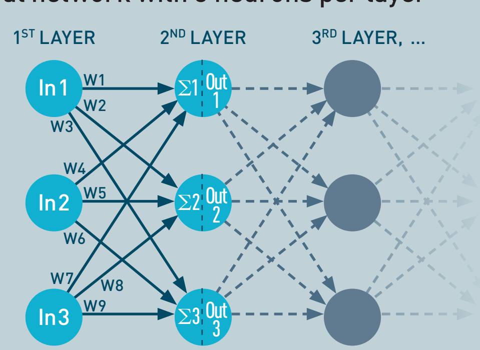
The power of learning

Both natural and artificial neural networks recognize patterns in data by adjusting the strength of connections between small processing units known as neurons. The link between each pair of neurons (known as a synapse in biological brains) is represented by a weight, with every neuron generating an output signal that depends on the sum of its weighted inputs. In the simplest case, the artificial neuron will "fire" when that sum exceeds some specific threshold. More generally, its output will be the result of a nonlinear function whose input is the weighted sum.

Neural networks used for machine learning are commonly arranged in layers: an input layer, several "hidden" layers, and an output layer, with data processed one layer at a time. If every layer contains N neurons, its processing can be represented by two steps. First, it multiplies an N-element input vector by an $N \times N$ weighting matrix, and then passes the result through a nonlinear function to generate another N-element output vector. That output serves as the next layer's input, and the process repeats until the network as a whole generates its N-valued output.

To be trained, a network is typically fed many examples of a certain kind of data set, such as the pixel values of photos of cats, along with a signal at the appropriate output, indicating "cat." With the weights initially assigned random values, the output signal is random. So the weights are adjusted to try and make the output more cat-like the next time around. This process is repeated many times until it reaches a steady state, with every input image of a cat then, in principle, being recognized as such by the network. At that point, the system has learned to distinguish a cat from a dog—or anything else.

Neural network with 3 neurons per layer



Going from one layer to the next is a two-step process:

1. Matrix multiplication

$$(\mathrm{In\,1} \;\; \mathrm{In\,2} \;\; \mathrm{In\,3}) \begin{pmatrix} W1 & W2 & W3 \\ W4 & W5 & W6 \\ W7 & W8 & W9 \end{pmatrix} = (\Sigma 1 \;\; \Sigma 2 \;\; \Sigma 3)$$

2. Nonlinear function

$$\left.\begin{aligned} \varnothing(\Sigma 1) &= \mathrm{Out\,1} \\ \varnothing(\Sigma 2) &= \mathrm{Out\,2} \\ \varnothing(\Sigma 3) &= \mathrm{Out\,3} \end{aligned}\right\} \text{(Out 1, Out 2, Out 3) then becomes input for next layer}$$

Opening up the spectrum

A very different approach to all-optical neural networking has been taken by Wolfram Pernice of the University of Münster, Germany, and colleagues. Rather than interfering individual coherent pulses of light, Pernice's team exploits wavelength-division multiplexing (WDM) to transport and sum multiple pulses at different wavelengths using single waveguides. They also use a phase-change material (PCM) for both linear summing and nonlinear firing. Employed in rewritable optical disks, this material transmits far more light when amorphous than when in a crystalline state.

Each neuron in a layer within this scheme uses a series of tiny ring-shaped resonators of varying diameters to tap light signals with corresponding wavelengths travelling together in a common waveguide. The signals at different wavelengths within a given neuron are each attenuated a certain amount by a piece of PCM in their path, and therefore weighted, before being combined in another waveguide. If the total power of all those signals exceeds a certain threshold, they then switch another piece of PCM, this time embedded in a resonator at the neuron's output.

When switched, this piece of PCM passes on a light pulse that would otherwise couple to the resonator, allowing the neuron to fire. The pulses from each of the neurons firing in that layer—each having a different wavelength—are then collected by another waveguide and constitute the input signals to the following layer. This process repeats layer by layer until pulses are generated at the device's output.

Pernice's group showed that it could train a single layer of four neurons, each with 15 inputs, to distinguish between four different pixilated letters, A, B, C and D (see diagram, p. 37). They also showed, using a simpler four-input neuron, how to carry out "unsupervised learning." Using a feedback loop, the neuron reinforced connections to inputs that contributed to a firing, allowing it to spot recurring but unflagged patterns within incoming data.

Pernice says that their system could potentially outpace electronic ANNs and is designed to be scaled up. But he cautions that manufacturing large quantities of very finely-tuned rings (whose resonant wavelengths would need to match to fractions of a nanometer) will not be easy. And Geoffrey Burr, a researcher at IBM in Almaden, California, adds that the neurons' firing rate will in practice be limited by the relatively slow recrystallization time of the PCM.

Problems with all-optical ANNs have led some groups to investigate optoelectronic schemes in which neurons convert signals from light into electricity and then back to light.

Researchers at the University of Münster, Germany, and the University of Oxford and University of Exeter, U.K., developed an optical chip (right) that implements four artificial neurons in photonic waveguides and ring resonators, and that can be taught to distinguish four different letters (left). WWU - Peter Leßmann / Johannes Feldmann

Other groups have proposed different all-optical schemes, each with its own strengths and weaknesses. Liu and several colleagues in Hong Kong have built an ANN with 22 neurons using spatial light modulators and Fourier lenses for matrix multiplication. For nonlinearity, they fix the strength of a laser probe passing through a gas of ultracold atoms using a second laser beam that tunes the relative population of atoms in different energy levels. Liu says they currently aim to realize at least 1000 neurons for solving practical problems such as image recognition, but adds that they need to make their system more efficient to contain costs.

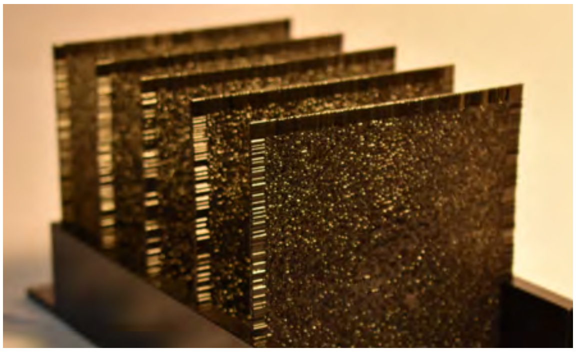
Researchers led by OSA Fellow Aydogan Ozcan at the University of California, Los Angeles, USA, meanwhile, have created hundreds of thousands of neurons from several very thin layers of polymer wafer. Using a computer model and 3D printing, they varied the thickness of the polymer such that it diffracts and directs incoming light to specific points on the final layer. Ozcan is confident that the system, tested out with terahertz radiation, can be modified to work in the visible or infrared, but acknowledges that reprogramming, which currently involves physically altering the layers, is tricky.

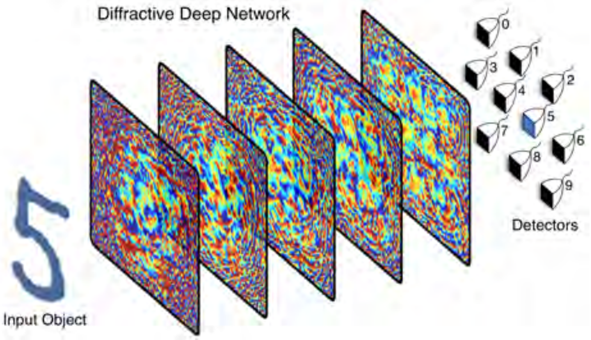
Electrons' helping hand

Problems with all-optical ANNs, in particular how to implement nonlinearity, have led some groups to investigate optoelectronic schemes in which neurons convert signals from light into electricity and then back to light—the electrical signals being amenable to nonlinear operations. Scientists at Princeton University, USA, for example, exploit WDM to connect multiple neurons with a single waveguide, while using an electro-optic modulator to introduce nonlinearity.

The Princeton scheme sets weights by heating micro rings, which former group member Bhavin Shastri, now at Queen's University in Kingston, Canada, says allows the weights to be changed very quickly (although they do require a continuous supply of energy). As such, he reckons the approach might enable learning on the fly, conceivably in the fast-changing environments of self-driving cars.

Another potential application is in compensating nonlinear distortions of signals in long-distance fiber optic cables. This can be done with conventional electronics, either deterministically or using neural networks, but high-speed transmission entails significant power consumption. The Princeton group, working





UCLA researchers identified handwritten digits by illuminating them and diffracting the light through a series of thin polymer wafers to trigger one of ten detectors. Ozcan Research Group/UCLA

with researchers at NEC Corp. in the United States and Japan, recently showed that a WDM-based photonic neural network could create an effective model of nonlinear distortions in a 10,000-kilometer-long stretch of trans-Pacific fiber accurately and efficiently.

Optoelectronic technology can also be used to implement a very different type of neural network known as a “reservoir computer”, in which most weights are never adjusted at all. This kind of network, which has significant practical potential, uses a random matrix to look for features in time-dependent data (see “A random reservoir,” p. 39).

The French company LightOn also exploits random matrices, but does so with what it calls an optical processing unit. This uses a camera to analyze laser light that has been encoded with image data via a micromirror array and that’s then passed through a diffusive medium. The scattered light interferes randomly on the camera to generate a speckle pattern, with the brightness of the pixels (a nonlinear function of the speckle field) used to identify specific features in the images. The company’s chief technology officer, Laurent Daudet, says that the processing unit—due to be made widely available online in April—is designed to complement digital processors, allowing quicker, more efficient matrix calculations.

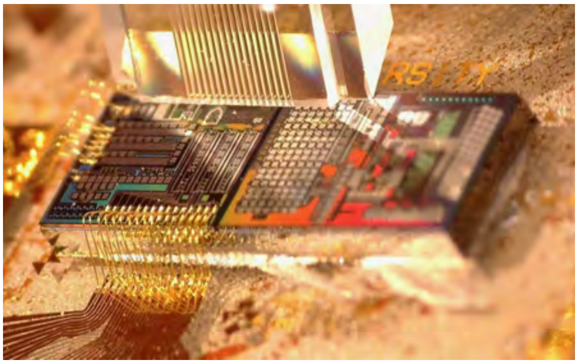
Thinking big

Despite the enthusiasm of many researchers toward optical ANNs, some scientists are skeptical that they can compete with digital computers. Rodney Tucker, an electrical engineer at the University of Melbourne, Australia, argues that electronic networks are easier to program and scale up. He also maintains that they are in fact more energy efficient, given the losses in optical systems—particularly for large-scale computations. “It is the energy per operation that matters,” he says.

Even those working on optical ANNs admit that significant hurdles remain. Shastri says that two things must happen before optoelectronic devices can compete with electronic ones. One is creating a scalable platform, such as a silicon substrate, that can support both photonic and electronic components. The other is the ability to integrate lasers onto such a platform cheaply. He notes that silicon lases only at very low temperatures, while indium phosphide lasers are more expensive.

For Charles Roques-Carmes at MIT, such hurdles need to be overcome in the next few years; otherwise rich multinationals will probably find a way to further improve electronic devices. “If optics is to make a difference it has to make it quite fast,” he says.

Nevertheless, with Moore’s law under threat as electronic circuits reach the limits of miniaturization, optical technologies have attracted significant interest and some investment, even by apparent competitors. The researchers at MIT have spun out two companies to develop chips that use optics to boost the speed of matrix multiplication. Lightelligence has raised at least US$10 million in funding, while Lightmatter has received



Micrograph image of a wirebonded photonic neural network chip from Princeton University's Lightwave Lab.
C. Huang et al., OFC 2020 / Princeton University Lightwave Lab

With Moore's law under threat as electronic circuits reach the limits of miniaturization, optical technologies have attracted significant interest and some investment.

more than US$30 million—including money from GV, a venture arm of Google's parent company Alphabet.

The research at Princeton has also led to the creation of a new company, Luminous Computing, which has attracted at least US$9 million in seed funding. Tait, who did his Ph.D. with the Princeton group, thinks this is a good sign for the field. "The start-ups being founded is important because there are now big teams of engineers working on these problems," he says.

But not all groups are thinking about commercial products. Tait is working on a NIST project headed by Shainline that is developing hardware designed, says Shainline, to "be scalable up to the human brain or beyond." That entails potentially building networks with tens of billions of neurons, which, Shainline says, means the neurons must be as efficient as possible to limit energy consumption (the human brain requiring a mere 20 W to operate). As such, the group has imposed a strict design criterion: communication between neurons must occur at the level of single photons.

The scheme on the drawing board relies on superconductors to detect photons and to update weights and sum inputs; semiconductors to generate the photons; and photonic components to distribute them—all at just a few degrees above absolute zero. Shainline acknowledges that combining these different components will not be easy, but says that he and his four colleagues will take their time to get the technology right.

He estimates they will have a single neuron ready in a couple of years' time, a functioning network with several hundred neurons on a single chip within about five years, and, if all goes well, multi-wafer systems comprising billions of neurons after a decade or more. At that point, he enthuses, they should have an "extraordinarily powerful" machine. "In the biological brain the neurons and synapses have rich complexity and most hardware projects miss out on that," he says. "But I think that is what makes the brain work so well." OPN

Edwin Cartlidge (edwin.cartlidge@yahoo.com) is a freelance science journalist based in Rome.

For references and resources, go online:
www.osa-opn.org/link/neural-nets

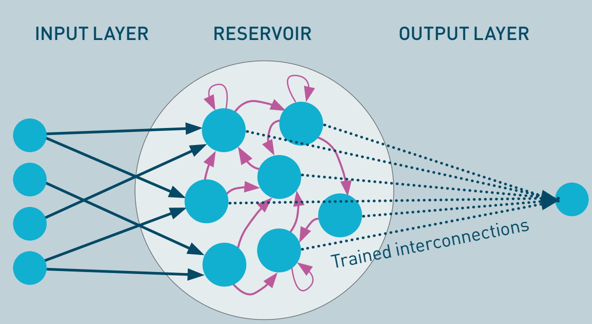
A random reservoir

To analyze data that are changing in time, a neural network can be made "recurrent" by connecting neurons not simply layer by layer, but to themselves and others some distance away. This lets signals travel backwards as well as forwards through the network, setting up feedback loops and the potential for a network "memory"—but also vastly complicating the nonlinear-weighting problem of training the network.

One way around this problem is a so-called reservoir computer. Such a computer consists of a recurrent network with randomized weights, as well as one additional layer of neurons at the input and another at the output. The idea is that, given a big enough network, somewhere within it there will be a region of connected neurons with the right weights to recognize signals of interest. Training involves a simple linear matrix multiplication to set the weights of the output neurons, while the weights within the recurrent network itself are left alone.

According to Guy Van der Sande of the Vrije Universiteit Brussel in Belgium, reservoir networks could prove particularly handy in signal analysis for optical routing, as they could eliminate the need to convert signals from light into electricity and then back to light, thereby saving time and energy. Another use could be reconstructing distorted signals from optical fibers or overcrowded cellular networks.

Toward another application, the team of Damien Rontani, University of Lorraine, France, has built a reservoir computer that can successfully distinguish between six human actions: walking, running, jogging, waving, clapping and boxing. The optoelectronic system uses a standard computer to assign values of pixels in a spatial light modulator on the basis of video footage of the six actions, plus camera to record light from an LED that is reflected off the modulator. The recorded images constitute the processed data, while the pixels represent the neurons – their values given a random component by the computer.



2020 OSA Awards and Medals

Please join us in congratulating the recipients of OSA's prestigious awards and medals. These honorees have made outstanding contributions to science, research, engineering, education, industry and society.

We also thank the dedicated nominators, references and award selection committee members for their support of this program. Visit www.osa.org/awards for more information.

ETH Zurich/Tom Kawara

Frederic Ives Medal/Jarus W. Quinn Prize

The highest award conferred by OSA, for overall distinction in optics

Ursula Keller

ETH Zürich, Switzerland

For fundamental contributions to ultrafast lasers technology, especially in the development of high peak and average power oscillators and important breakthroughs in attosecond science

Ursula Keller received a physics "Diplom" from ETH Zürich, Switzerland, and a Ph.D. in applied physics from Stanford University, USA. A tenured professor of physics at ETH Zürich, she currently serves as a director of the National Center of Competence in Research Molecular Ultrafast Science and Technology (NCCR MUST), an interdisciplinary research program launched by the Swiss National Science Foundation to bring together Swiss research groups working in ultrafast science across the fields of physics, chemistry and biology.

Before joining ETH, Keller was a member of the technical staff at AT&T Bell Laboratories, USA. She is the only individual to receive OSA's Frederic Ives Medal/Jarus W. Quinn Prize, Charles H. Townes Award and Joseph Fraunhofer Award/Robert M. Burley Prize. She is a Fellow of OSA, SPIE, IEEE, the European Physical Society and the International Academy of Photonics and Laser Engineering, and a member of the Royal Swedish Academy of Sciences, Academy Leopoldina and Swiss Academy of Technical Sciences. She has served the community through work on international advisory boards and conference committees, editorial boards and association boards, including the OSA Board of Directors.

Keller's research interests include exploring and pushing the frontiers in ultrafast science and technology. She invented the semiconductor saturable absorber mirror (SESAM), which enabled passive mode-locking of diode-pumped solid-state lasers and established ultrafast solid-state lasers for science and industrial applications. She has pushed the frontier of few-cycle pulse generation and full electric field control at petahertz frequencies. She pioneered frequency comb stabilization from mode-locked lasers, which was noted by the Nobel committee for Physics in 2005. In addition, she invented the attoclock, which measured the electron tunneling delay time, and observed the dynamical Franz-Keldysh effect in condensed matter for the first time.

Esther Hoffman Beller Medal

In recognition of outstanding contributions to education in optical science and engineering

Julio C. Gutiérrez-Vega

Tecnológico de Monterrey, Mexico

For exceptional commitment to optics education through extraordinary academic mentoring and teaching, the development of original, engaging teaching materials and the establishment of a world-class optics graduate program

Julio Gutiérrez obtained his Ph.D. in optics from the National Institute of Astrophysics, Optics and Electronics (INAOE), Mexico. He is currently a professor in the physics department at the Tecnológico de Monterrey. Gutiérrez has published 103 journal articles that report about 3,700 citations, with an h-index of 31. He is an OSA Fellow and has served on the editorial committees of *Optics & Photonics News* and *Optics Express*.

Gutiérrez's research interests focus mostly on light propagation, laser beam shaping and fractional optics. For more than 20 years, he has taught courses to undergraduate students, including electromagnetism, quantum mechanics, mathematical methods and computational physics. Gutiérrez has been the thesis advisor of eight Ph.D. students, the founding advisor of the OSA Student Chapter at Tecnológico de Monterrey and a promoter of the institution's postgraduate program in optics.

Max Born Award

In recognition of contributions to physical optics

Nader Engheta

University of Pennsylvania, USA

For pioneering contributions to optical metamaterials and nanoscale optics

Nader Engheta received his B.S. degree from the University of Tehran, Iran, and M.S. and Ph.D. degrees from the California Institute of Technlology, USA. He has received honorary doctoral degrees from Aalto University, Finland, the University of Stuttgart, Germany, and Kharkov Polytechnic Institute, Ukraine. Currently, he is the H. Nedwill Ramsey Professor at the University of Pennsylvania. He is a Fellow of OSA, the American Physical Society, IEEE, the Materials Research Society, SPIE, the American Association for the Advancement of Science, and the International Union of Radio Science.

Engheta is one of the original pioneers of the field of metamaterials, beginning with his early work in the 1980s on complex and chiral media, and continuing with his many contributions to optics and electrodynamics. These include the development of the fields of near-zero-index optics, optical nanocircuitry and analog computing using materials, plasmonic cloaking, and one-atom-thick metamaterials. His current research activities span a broad range of areas including photonics, metamaterials, nanoscale optics, microwaves, graphene optics, imaging and sensing inspired by eyes of animal species, microwave and optical antennas and physics, and engineering of fields and waves.

Stephen D. Fantone Distinguished Service Award

In recognition of outstanding service to OSA

Susan Houde-Walter

LMD Power of Light Corp., USA

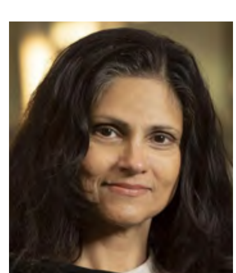
For outstanding service to the society through numerous advisory and leadership roles, including 2005 President, Board of Directors Member and Chair of the Optics & Photonics News Editorial Advisory Committee

Susan Houde-Walter received her Ph.D. at the University of Rochester, USA, where she subsequently joined the faculty and earned tenure as a professor of optics. She currently runs LaserMaxDefense (LMD), a laser system manufacturer that she co-founded. She is an inventor on 26 patents, and has published 100+ papers and invited talks on optoelectronic design and optical materials. She is an OSA Fellow.

Houde-Walter began her OSA service as a graduate student, and served later with various program and publication committees. She served on the OSA Board from 1994 to 1996, and was elected OSA President in 2005. Her development of international leadership, monthly essays in *Optics & Photonics News*, interviews of the 2005 Nobel Prize Laureates, executive team development and unprecedented fundraising success characterized her year as OSA President. She now serves on the OSA Strategic Planning Committee.

Michael S. Feld Biophotonics Award

In recognition of innovative and influential contributions to the field of biophotonics, regardless of career stage



Nimmi Ramanujam

Duke University, USA

For advances in precision diagnostics and therapeutics to address global disparities in cervical and breast cancer management and mortality

Nimmi Ramanujam received her Ph.D. in biomedical engineering from The University of Texas, Austin, USA. She held positions at The University of Texas, Austin, USA, the National Institutes of Health, USA, the University of Pennsylvania, USA, and University of Wisconsin, Madison, USA, before joining Duke University. She is a Fellow of OSA, SPIE, the American Institute for Medical and Biological Engineering and the National Academy of Inventors.

Ramanujam is an innovator, educator and entrepreneur. Her mission is to develop technology that will have wide-reaching impact in women's health. Her research on women's cancers has centered on translational and laboratory research of relevance to breast and cervical cancer. In the case of cervical cancer prevention, her focus is to develop strategies that reduce attrition to treatment including early screening and diagnostics. In the breast cancer care cascade, she has focused on molecular and metabolic imaging to prevent recurrence. A third area in her research program focuses on low-cost ablative strategies for local control of cancer in resource-limited settings.

Joseph Fraunhofer Award/ Robert M. Burley Prize

In recognition of significant research accomplishments in the field of optical engineering

Jannick Rolland

University of Rochester, USA

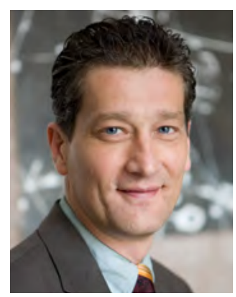
For numerous creative and innovative applications in several fields of optical engineering including Astronomy, Medical Imaging, Augmented & Virtual Reality, Image Science, and Freeform Optics

Jannick Rolland earned an optical engineering diploma from the Institut D'Optique Théorique et Appliquée, France, and her M.S. and Ph.D. in optical science from the University of Arizona, USA. She is the Brian J. Thompson Professor in Optical Engineering at the University of Rochester, director of the Center for Freeform Optics (CeFO), and CTO and co-founder the biotech company LighTopTech. She is a Fellow of OSA, SPIE, and the NYSTAR Foundation, and a recipient of the OSA David Richardson Medal.

Rolland's work brings novel optical engineering solutions to a wide range of fields. She designed the optics for SPOT4, a satellite that monitored the earth. In medical imaging, she developed the mathematics to describe the "lumpy background" noise in medical images, giving rise to a widely-adopted method to assess image quality in diagnostic instruments. She invented Gabor-domain optical coherence microscopy for high-definition 3D imaging, and is an early contributor to augmented reality while advancing freeform optics, a disruptive technology poised to penetrate a variety of markets.

Joseph W. Goodman Book Writing Award

In recognition of a recent and influential book in the field of optics and photonics that has contributed significantly to research, teaching, business or industry (co-sponsored by SPIE)



Irving J. Bigio

Boston University, USA

Sergio Fantini

Tufts University, USA

Authors of *Quantitative Biomedical Optics: Theory, Methods, and Applications* (Cambridge University Press, 2016)

Irving J. Bigio received his Ph.D. from the University of Michigan at Ann Arbor, USA. He has been a professor of biomedical engineering and electrical and computer engineering at Boston University for the past 22 years. He is primarily interested in using biomedical optics to develop clinical and research applications of optical technologies. His lab was founded in 2001 and focuses on clinical diagnostics based on elastic scattering spectroscopy, on laboratory applications to monitor sub-cellular dynamics in vitro, and on novel methods to image neuronal activation patterns in label-free neural tissues. He has mentored numerous graduate and undergraduate students, co-authored over 200 scientific publications, and is an inventor on nine patents. He is a Fellow of OSA, SPIE, the American Institute for Medical & Biological Engineering, and the American Society for Lasers in Medicine and Surgery.

Sergio Fantini received his Ph.D. from University of Florence, Italy. He has been a professor of biomedical engineering at Tufts University for the past 18 years. His research interests lie in the area of biomedical optics, specifically in diffuse near-infrared spectroscopy and the imaging of biological tissues. His research laboratory aims to develop noninvasive applications of diffuse optics to assess cerebral perfusion and brain activity, detect breast cancer, monitor response to neoadjuvant chemotherapy, and quantify skeletal muscle oxygenation. He has co-authored about 200 scientific publications and is an inventor on eleven patents. He is a Fellow of OSA, SPIE and the American Institute for Medical and Biological Engineering.

Nick Holonyak Jr. Award

In recognition of contributions to optics based on semiconductor-based devices and optical materials, including basic science and technological applications

Kei May Lau

Hong Kong University of Science & Technology (HKUST), Hong Kong

For significant contributions to heteroepitaxy of compound semiconductors on silicon for future integrated lasers and advancing the field of light-emitting diode microdisplays

Kei May Lau received B.S. and M.S. degrees in physics from the University of Minnesota, Minneapolis, USA, and her Ph.D. degree in electrical engineering from Rice University, USA. She is currently the Fang Professor of Engineering in the HKUST electrical and computer engineering (ECE) department. Previously Lau was on the ECE faculty at the University of Massachusetts Amherst, USA, and initiated the metal-organic chemical vapor deposition (MOCVD), compound semiconductor materials and devices programs. Lau is a Fellow of OSA, the Hong Kong Academy of Engineering Science and IEEE.

Lau's work focuses on the development of monolithic telecommunication-band diode lasers directly grown on (001) silicon substrates. She combines innovation in MOCVD-based growth of heterostructure materials with insights into both device physics and fabrication to improve device performance, for effective multi-device integration. The benefits of integrating high-performance III–V-based devices onto a silicon substrate strongly leverages the enormous capabilities and infrastructure of the Si CMOS industry, extending them to photonic and electronic integrated devices/circuits at high frequencies.

Robert E. Hopkins Leadership Award

In recognition of significant impact on the field of optics or a significant contribution to society

Roberta Ramponi

IFN-CNR and Politecnico di Milano, Italy

For leadership in the promotion and dissemination of optics and light-based technologies, and outstanding contributions in establishing a strategic vision for research and innovation in photonics in Europe

Ramponi received her M.Sc. in physics and Specialization Diploma in medical physics at the University of Milano, Italy. She was a researcher at the National Research Council (CNR) in Milano, Italy, before becoming a professor of physics at the Politecnico di Milano. She also serves as the director of the CNR Institute for Photonics and Nanotechnology (IFN).

Ramponi's research has covered a wide range of activities in the fields of optics, photonics and related applications. Throughout her career, she has served the optics and photonics community, bringing strategic vision and leadership to national and international societies and organizations. She served as the President of the European Optical Society from 2006 to 2008 and is currently President of the International Commission for Optics (ICO). She also serves on the Executive Board of the European Public Private Partnership Photonics21. Ramponi has worked to support gender balance; to bridge the gap between the scientific community, policy makers and the general public; and to develop successful initiatives in education, training and outreach.

Edwin Land Medal

In recognition of pioneering work empowered by scientific research to create inventions, technologies and products (co-sponsored by the Society for Imaging Science and Technology)

Eric R. Fossum

Thayer School of Engineering at Dartmouth, USA

For the invention and commercialization of advanced CMOS optical sensor imaging technology and the Quanta Image Sensor, and for university entrepreneurial and national young inventor training activities

Eric R. Fossum received his M.Sc. degree and Ph.D. in engineering and applied science from Yale University, USA. After working at the NASA Jet Propulsion Laboratory (JPL) at Caltech, USA, he co-founded several startups and served as CEO. He is currently the Krehbiel Professor for Emerging Technologies at the Thayer School of Engineering at Dartmouth. He has published over 300 technical papers and holds over 170 U.S. patents. He is an OSA and IEEE Fellow, a National Inventors Hall of Fame inductee and a Queen Elizabeth Prize Laureate.

Fossum is a solid-state image sensor device physicist and engineer, who invented the CMOS active pixel image sensor with intra-pixel charge transfer while at JPL, the basis for all modern CMOS image sensors. He further developed and commercialized the technology with colleagues at their startup, Photobit. He later invented the photon-counting Quanta Image Sensor. At Dartmouth, he developed the QIS technology with his students and co-founded Gigajot. He works with students and faculty to foster innovation and entrepreneurial thinking at Dartmouth and with the NIHF Camp Invention program.

Sang Soo Lee Award

In recognition of outstanding leadership in founding or growing the optics and photonics community locally (co-sponsored by the Optical Society of Korea)

Ajoy Ghatak

NASI (The National Academy of Sciences India), Prayagraj, India

For his seminal role in the development of fiber optics and guided-wave photonics and for pioneering optics education in India

Ajoy Ghatak received his M.Sc. from Delhi University, India, and a Ph.D. from Cornell University, USA. He was a professor at the Indian Institute of Technology (IIT), Delhi, India, and is currently the NASI Meghnad Saha Distinguished Professor. He is an OSA Fellow and recipient of the OSA Esther Hoffman Beller Medal. He was the President of Optical Society of India.

Ghatak nurtured the Fiber Optics Group and master's program at IIT Delhi. He has organized numerous workshops and short courses, and has published extensively in the area of optical waveguides and quantum well structures. His methods have been used by many researchers. He is author and co-author of many books including textbooks on optics (translated to Chinese and Persian), fiber optics and optical electronics.

Emmett N. Leith Medal

In recognition of seminal contributions to the field of optical information processing

Mitsuo Takeda

Utsunomiya University, Japan

For contributions to the fields of optical information processing and holography through the inventions of Fourier fringe analysis and coherence holography

Mitsuo Takeda received a M.E. and Ph.D. in applied physics from the University of Tokyo, Japan. He is professor at the Center for Optical Research & Education (CORE), Utsunomiya University, and professor emeritus at the University of Electro-Communications (UEC), Japan. He has been a visiting scholar at Stanford University, USA, and an Alexander von Humboldt Guest Professor of the Institut für Technische Optik, Universität Stuttgart, Germany. Prior to joining the faculty of UEC in 1977, he worked for Canon Inc. He is an OSA Fellow.

Takeda is the inventor of the Fourier-transform method for fringe analysis (also known as Fourier fringe analysis), which is used widely in optical metrology. Its applications expand beyond traditional optical interferometry and profilometry, to the measurement of extreme physical phenomena that involve ultrashort optical pulses, extremely small atomic displacement, and unconventional interferometry with electron wave, X-ray and EUV sources. He has also conducted seminal work on coherence holography for coherence synthesis and unconventional imaging.

Ellis R. Lippincott Award

In recognition of contributions to vibrational spectroscopy (co-sponsored with the Coblentz Society and the Society for Applied Spectroscopy)

Volker Deckert

Leibniz Institute of Photonic Technology, Jena, Germany

For ongoing contributions to high-resolution Raman spectroscopy, in particular the realization of tip-enhanced Raman spectroscopy, allowing label-free structural surface characterization down to the single-molecule level

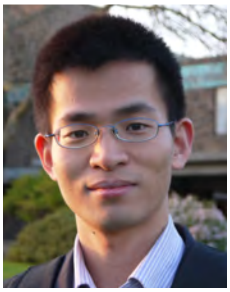
45th Anniversary Lippincott Award

Volker Deckert obtained his Ph.D. from the University of Würzburg, Germany. After a postdoc at the University of Tokyo, Japan, he started researching near-field optical spectroscopy, first at the ETH Zurich, Switzerland, and then throughout Germany, in Dresden, Dortmund and Jena. He is a department head at Leibniz Institute of Photonic Technology and a professor for physical chemistry at the Friedrich-Schiller University, Germany.

Deckert's research focuses on Raman spectroscopy, near-field optical microscopy, and plasmon enhancement. The major goal is to extend the limits of spatial resolution for label-free techniques, particularly for methods based on tip-enhanced Raman scattering (TERS). His research is mainly driven by questions related to chemical and/or bio-related problems that require structural information at the highest possible resolution. These studies then help to understand underlying theoretical concepts of the often surprising lateral resolution.

Adolph Lomb Medal

In recognition of noteworthy contributions made to optics at an early career stage



Chao-Yang Lu

University of Science and Technology of China, China

For significant contributions to optical quantum information technologies, especially on high-performance single-photon sources, quantum teleportation and optical quantum computing

80th Anniversary Lomb Medal

Chao-Yang Lu received a B.S. degree from the University of Science and Technology of China and his Ph.D. in physics from the Cavendish Laboratory, University of Cambridge, U.K. He is currently a professor of physics at the University of Science and Technology of China. He is an OSA Fellow.

Lu's research focuses on quantum foundations, quantum computation, and quantum communications. He and his colleagues are developing scalable quantum light sources based on spontaneous parametric down-conversion and microcavity-coupled quantum dots. They created sources of single and entangled photons, which simultaneously have near-unity indistinguishability and high extraction efficiency. Using these quantum light sources, they demonstrated record numbers of 12-photon entanglement, 20-photon boson sampling, astronomical-scale quantum interference, and quantum teleportation of multiple degrees of freedom and high-dimensional states of a single photon.

C.E.K. Mees Medal

In recognition of an original use of optics across multiple fields

Daniel J. Blumenthal

University of California Santa Barbara (UCSB), USA

For innovation in ultra-low-loss photonic integrated circuits and their application to ultra-low linewidth lasers, optical communications, signal processing, optical gyroscopes and atom cooling

Daniel Blumenthal received his Ph.D. degree from the University of Colorado, Boulder, USA, his M.S.E.E. from Columbia University, USA, and his B.S.E.E from the University of Rochester, USA. He is currently a professor in the Department of Electrical and Computer Engineering at UCSB, director of the Terabit Optical Ethernet Center, and heads the Optical Communications and Photonics Integration group. He is co-founder of Packet Photonics Inc. and Calient Networks, both in USA. He holds 23 patents, has published over 460 papers, and is co-author of *Tunable Laser Diodes and Related Optical Sources*. He is a Fellow of OSA, IEEE and the National Academy of Inventors.

Blumenthal has pioneered ultra-low-loss silicon nitride and tantala waveguides, photonic integrated circuits and their applications. His work includes integrated ultra-narrow, sub-Hz-linewidth SBS lasers, highly integrated indium phosphide photonic circuits, fiber optic communications and optical packet switching, optical gyroscopes, microwave photonics, optical signal processing and ultrafast techniques, and extending photonic integrated technologies into the visible wavelength range for applications including atom cooling, timekeeping, and Raman spectroscopy.

William F. Meggers Award

In recognition of outstanding work in spectroscopy

Tony F. Heinz

Stanford University and SLAC National Accelerator Laboratory, USA

For seminal studies of the properties and dynamics of surfaces, interfaces, and nanoscale materials by diverse spectroscopic techniques, including through the development of powerful new methods

Tony Heinz received a B.S. in physics from Stanford University, USA, and a Ph.D. in physics from the University of California, Berkeley, USA. He is a professor of applied physics and photon science at Stanford University and the Associate Laboratory Director for Energy Sciences at SLAC National Accelerator Laboratory. Previously, he was a research staff member at the IBM Watson Research Center, USA, and a professor of physics and electrical engineering at Columbia University, USA. He is a Fellow of OSA and served as OSA President in 2012.

Heinz has developed a wide range of spectroscopic techniques to examine the properties and dynamics of nanoscale systems. These methods include interface-sensitive nonlinear spectroscopy and time-resolved approaches, such as terahertz time-domain techniques. The measurement techniques have been applied to elucidate the electronic, optical and chemical properties of 0-, 1-, and 2-dimensional materials and interfaces. The research would not have been possible without the insight and hard work of more than 70 graduate students and postdocs over the years.

David Richardson Medal

In recognition of significant contributions to optical engineering, primarily in the commercial and industrial sector

G. Michael Morris

RPC Photonics, Inc., and Apollo Optical Systems, Inc., USA

For contributions to the commercial development of diffractive and beam-shaping optics, along with significant achievements in entrepreneurship, the founding and development of two highly successful companies, and ongoing support of education in optical engineering

G. Michael Morris received his B.S. degree from the University of Oklahoma, USA, and his M.S. and Ph.D. degrees from the California Institute of Technology, USA. He was the CEO and co-founder of RPC Photonics and is currently serving as the CEO of Apollo Optical Systems (AOS). Prior to RPC and AOS, he was a professor of optics at the Institute of Optics, University of Rochester, USA. He is an OSA Fellow and recipient of the OSA Joseph Fraunhofer Award/Robert M. Burley Prize and Stephen D. Fantone Distinguished Service Award. He served as OSA President in 2003 and as President of the OSA Foundation from 2009 to 2015.

Morris' research has spanned a wide variety of topics in statistical optics, optical information processing, quantum-limited imaging, automatic pattern recognition, and diffractive- and micro-optics technology. His current research/development interests include optical beam-shaping components, with a particular emphasis on 3D-imaging and -sensing systems for consumer electronics, robot vision, autonomous vehicles and surveillance markets. He holds over 30 U.S. patents and has published more than 70 referred journal articles, three book chapters and numerous conference proceedings.

Call for 2021 Award and Medal Nominations

Join us in recognizing the field's technical, research, engineering, education, business, leadership and service accomplishments. Nominations for most 2021 awards and medals are due **1 October**. Please take advantage of this unique opportunity to recognize the extraordinary efforts of your colleagues. Visit www.osa.org/AwardCategories to find the most appropriate recognition.

Kevin P. Thompson Optical Design Innovator Award

In recognition of contributions to lens design, optical engineering or metrology at an early career stage

Aaron Bauer

University of Rochester, USA

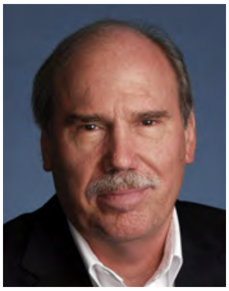
For theoretical, creative, and innovative design methods for freeform optics

Aaron Bauer received a B.S. degree in physics from University of Wisconsin–Eau Claire, USA, and a Ph.D. in optics from the Institute of Optics at the University of Rochester, USA. He has since joined the Institute of Optics full-time as a research engineer investigating the latest optical design topics and mentoring graduate students.

His research interests stem from his doctoral work, where he focused on applying freeform surfaces to optical designs in a practical and efficient manner. His current work includes utilizing freeform surfaces to improve the performance and packaging of optical systems and metasurfaces to enable both form and function. Bauer is also involved in more conventional optical system design for a variety of applications.

Edgar D. Tillyer Award

In recognition of distinguished work in the field of vision



Wilson Geisler

University of Texas at Austin, USA

For pioneering theories of optimal visual processing that bring together scene statistics, physiological constraints, and task requirements to gain a new understanding of perceptual functions and eye movements

Wilson (Bill) Geisler obtained an undergraduate degree in psychology from Stanford University, USA, and a Ph.D. degree in mathematical and experimental psychology from Indiana University, USA. Geisler is currently the David Wechsler Regents Chair in Psychology at the University of Texas at Austin. He is a Fellow of OSA and the Society of Experimental Psychologists, and a member of the National Academy of Sciences.

His research combines behavioral studies, neurophysiological studies, studies of natural stimuli, mathematical analysis and computational modeling. He is best known for his work on the mathematics of how to perform perceptual tasks optimally ("ideal observer theory"), on the relationship between the statistical properties of natural stimuli and visual performance, on the nature of eye movements in natural tasks, and on the relationship between visual performance and the neurophysiology of the visual system.

Charles Hard Townes Medal

In recognition of contributions to quantum electronics

Toshiki Tajima

University of California Irvine, USA

For seminal contributions in broad and novel plasma physics and laser-based accelerator physics, introducing the concept of Laser Wakefield Acceleration

40th Anniversary Townes Medal

Toshiki Tajima received his M.Sc. degree in physics from University of Tokyo, Japan, and a Ph.D. in physics from the University of California Irvine, USA. He is the Norman Rostoker Chair professor at the University of California at Irvine, and the deputy director of the International Center for Zetta- and Exawatt Science and Technology (IZEST). He served as Chair of the APS Subdivision of Plasma Astrophysics and the International Committee for Ultrahigh Intensity Lasers (ICUIL). He is the former Director General of Kansai Photon Science Institute and the Jane and Roland Blumberg professor at University of Texas at Austin, USA.

In 1979, Tajima suggested the theory of the formation of a wakefield behind an ultra-short intense laser pulse and its subsequent acceleration of particles to high energies. This concept spurred the creation of high-field science. He was among the first in a team that demonstrated wakefield acceleration experimentally. Its applications include the compact generation of high-energy electrons, ions, and X-rays on ultrafast time scales and cancer therapy.

John Tyndall Award

In recognition of contributions to fiber optic technology (co-sponsored with the IEEE Photonics Society)

Roel Baets

Ghent University, Belgium

For seminal research in silicon photonics and for driving the foundry model in this field

Roel Baets received M.Sc. degrees from Ghent University, Belgium, and Stanford University, USA, and a Ph.D. from Ghent University. Since 1989 he has been a professor in the Faculty of Engineering and Architecture at Ghent University, where he founded the Photonics Research Group. He was previously a part-time professor at Delft University of Technology and Eindhoven University of Technology, Netherlands. He is also associated with IMEC, Belgium. Baets is a Fellow of OSA, IEEE and the European Optical Society. He is also a member of the Royal Flemish Academy of Belgium for Sciences and the Arts and is currently a director-at-large on the OSA Board of Directors.

Baets has mainly worked in the field of integrated photonics, making contributions to research on photonic integrated circuits, both in III–V semiconductors and in silicon and silicon nitride, as well as their applications in telecom, datacom and sensing. In recent years, his research has focused on medical- and environmental-sensing applications of silicon photonics.

Herbert Walther Award

In recognition of distinguished contributions in quantum optics and atomic physics as well as leadership in the international scientific community (co-sponsored with Deutsche Physikalische Gesellschaft)

Eugene Polzik

Københavns Universitet, Denmark

For pioneering experimental contributions to quantum optics including the demonstration of spin squeezing and entanglement of atomic ensembles, quantum teleportation between light and matter, a quantum memory for light, and hybrid atomic-mechanical coupling

Eugene Polzik received M.Sc. and Ph.D. degrees in physics from Leningrad (Saint Petersburg State) University, Russia. Upon completion of his Ph.D., he became an associate professor of physics at the Mining Institute in Leningrad. Since then, he has held a number of positions at the California Institute of Technology, USA; the University of Aarhus, Denmark; the Institute Henri Poincaré, France; and the Institute for Photonic Sciences in Barcelona, Spain. He is a Fellow of OSA, the American Physical Society and the Institute of Physics, and a member of the Royal Danish Academy of Sciences and Letters.

Polzik has published more than 160 papers in refereed journals and given over 150 plenary and invited talks. His research has helped to lead the development of quantum optics throughout Europe, which includes his leadership of the Quantum Information Processing and Communication in Europe (QUROPE) project from 2006-2009. In Denmark, he established the first quantum optics lab, and later the Danish Center for Quantum Optics (QUANTOP) at the University of Copenhagen.

R.W. Wood Prize

In recognition of an outstanding discovery, scientific or technological achievement or invention

John Dudley

Université Bourgogne Franche-Comté & CNRS FEMTO-ST, France

For elucidating the fundamental aspect of supercontinuum generation through careful study of phase stability and opening the way to compact supercontinuum sources and their numerous applications

45th Anniversary Wood Prize

John Dudley received his Ph.D. from the University of Auckland, New Zealand, and worked both at Auckland and the University of St Andrews, Scotland, U.K., before being appointed professor at the Université Bourgogne Franche-Comté in 2000. He has led a number of national and international initiatives in both research and the public engagement of science. He is a Fellow of OSA, SPIE, IEEE and the European Optical Society and an Honorary Fellow of the Royal Society of New Zealand Te Apārangi. In 2015, he was awarded OSA's Robert E. Hopkins Leadership Award.

Dudley's research covers a wide range of topics in ultrafast and nonlinear optics. He pioneered the use of advanced measurement techniques to characterize complex pulse propagation in nonlinear fiber optics, and contributed especially to the development of a clear understanding of the physics of fiber supercontinuum generation. Other areas of interest include ultrafast self-similarity and the study of optical rogue waves and their oceanic counterparts.

Thank You, 2020 Award Selection Committee Members!

Many thanks to the volunteers who served on the award selection committees. We greatly appreciate your time, effort and expertise.

Frederic Ives Medal/Jarus W. Quinn Prize Committee

Susana Marcos, Chair
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Alain Aspect
Institut d'Optique, France

Anna Consortini
Universitá degli Studi di Firenze, Italy

Hideo Kuwahara
Fujitsu Laboratories Ltd., Japan

Marija Strojnik
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Lan Yang
Washington University in St. Louis, USA

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Sergio Fantini
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Janice Hudgings
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Bettina Heim
OHB System, Germany

Bahaa Saleh
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Eva M. Sevick-Muraca
UT Health Science Center at Houston, USA

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Pascal Picart
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(Joint with SPIE)

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Brillnics Japan Inc., Japan

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(Joint with IS&T)

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LGS Innovations LLC, USA

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Kidger Optics Associates, U.K.

Jingyu Lin
Texas Tech University, USA

Anna Claire Peacock
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Paul Westbrook
OFS Laboratories, USA

Dan-Xia Xu
National Research Council Canada, Canada

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Sacher Lasertechnik GmbH, Germany

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Bojan Resan
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Ellen Campbell Carter
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Karen Mary Hampson
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Mitsuo Ikeda
Rajamangala Univ. of Tech., Thailand

Charles Hard Townes Medal Committee

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Universidade Federal do Rio de Janeiro, Brazil

Natalia Litchinitser, Past Chair
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Yoko Miyamoto
University of Electro-Communications, Japan

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Orazio Svelto
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John Tyndall Award Committee

(Joint with IEEE Photonics Society)

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Hebrew University of Jerusalem, Israel

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Pharad, USA

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(Joint with Deutsche Physikalische Gesellschaft)

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Quaid-I-Azam University, Pakistan

Manijeh Razeghi*
Northwestern University, USA

R.W. Wood Prize Committee

Valeri Rodriguez-Fajardo, Chair
University of Witwatersrand, South Africa

Thomas Haslett, Past Chair
Avo Photonics Inc., Canada

Demetrios Christodoulides
University of Central Florida, CREOL, USA

Kishan Dholakia
University of St. Andrews, U.K.

Christina Lim
University of Melbourne, Australia

Rachel P.C. Won
Nature Photonics, U.K.

**Denotes OSA representative on joint society committees*

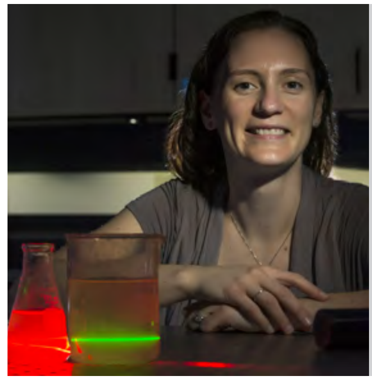
OSA Update

Thank You, Editors

We are happy to announce that the following individuals were recently appointed as new editors: *Applied Optics*: **Barbara Bulgarelli**, Directorate for Sustainable Resources JRC-EC (Ispra), Italy. *JOCN*: **Marija Furdek**, Chalmers University of Technology, Sweden. JOSA A: **Felipe Guzman**, University of Arizona, USA. *Optica*: **Olivier Pfister**, University of Virginia, USA. *Optics Express*: **Vittorio Passaro**, Politecnico di Bari, Italy; **Regina Soufli**, Lawrence Livermore National Laboratory, USA; **Lyuba Titova**, Worcester Polytechnic Institute, USA. *Optics Letters*: **Thomas Weiss**, Universität Stuttgart, Germany.

We thank the following editors for agreeing to serve a second term: *Optics Express*: **Yan Li**, Shanghai Jiao Tong University, China; **Xiaodong Yang**, Missouri University of Science and Technology, USA.

We thank the following editors, who have recently finished their terms, for their years of service: *Optica*: **Jesper Mørk**, Technical University of Denmark, Denmark; **Halina Rubinsztein-Dunlop**, University of Queensland, Australia; **Konstantin Vodopyanov**, CREOL, University of Central Florida, USA; **Changhuei Yang**, California Institute of Technology, USA. *Optics Letters*: **Benfeng Bai**, Tsinghua University, China; **Riccardo Borghi**, Universitá degli Studi Roma Tre, Italy. *Optical Materials Express*: **Kenneth Schepler**, CREOL, University of Central Florida, USA.



Vanderbilt University

OSA Fellow Stories

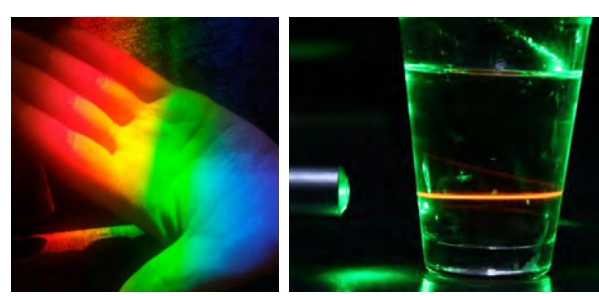
"Failure is a great motivator and a great teacher, and now I know that there is success and learning, rather than success and failure," says OSA Fellow **Melissa Skala**, University of Wisconsin-Madison, USA. Skala leads the Optical Microscopy in Medicine Lab at the Morgridge Institute for Research. Read more about Skala and other Fellows at **www.osa.org/fellowprofiles**.

OSA Virtual Meetings

From 20 to 23 April, we embraced our value of inclusivity and held the OSA Biophotonics Congress: Biomedical Optics as a virtual event, free-of-charge to all. Plenary Speaker Steven LeBoeuf, President of Valencell, Inc., USA gave a talk on blood pressure monitoring via wearable photoplethysmography and machine learning. This congress originally planned for 425 in-person attendees, but the virtual format drew 3,600 virtual attendees. Recordings of the talks are available on OSA Publishing's Digital Library.

Upcoming virtual congresses: OSA Imaging and Applied Optics Congress/Optical Sensors and Sensing Congress (22-26 June) and the OSA Advanced Photonics Congress (13-16 July). Both will be presented virtually with no cost for participants and a US$100 publication fee for contributing authors.

Optics Magic for the Whole Family



OSA

School and office closures require us to combine our work and home lives as never before. School closures mean that many of us are also entertaining and educating our kids in addition to managing our other obligations.

With that in mind, we teamed up with OSA Fellow and Esther Hoffman Beller Medal winner **Judy Donnelly** and OSA Senior Member **Nancy Magnani** to bring optics lessons directly to people's homes.

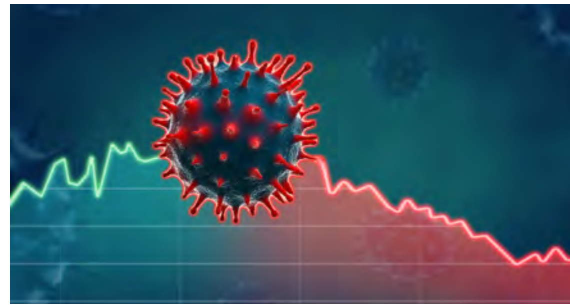
Through four live webinars—Colors of Light, Light and Shadows, Reflecting on Light, and Twisting Light—Donnelly and Magnani explored the science of light. By using materials you can find in your home, they helped parents and kids learn how light behaves and interacts with the world around us. The webinars are now available on **www.osa.org/EducationOutreach**.

We Are On!

Throughout the global pandemic crisis, OSA has remained determined to provide access to scientific content and professional-development resources, as well as to keep the optics and photonics community connected. As part of this effort, we launched an expanded suite of webinars, available at **www.osa.org/WeAreOn**. Access content live or check out past programs on demand when you have the time. Tap these resources to work, learn and wonder while continuing to engage with colleagues around the world.

Register for upcoming OSA Technical Groups webinars, such as "Individual Differences in Color Vision" (4 June) and "Zero Index on a Photonic Chip" (8 June), as well as for the OSA Foundation's Innovation School webinars, available for streaming in July. For those interested in sharing optics with the whole family, OSA's Optics 4 Kids provides activities designed for three different age groups.

If there is content you're interested in, then let us know at **weareon@osa.org**.



Getty Images

Navigating a Business Through COVID-19

How do optics and photonics companies manage through the pandemic and the ensuing economic downturn? OIDA launched an ongoing webinar series in April that addresses this question, drawing on the collective wisdom within the community as well as outside experts to share best practices and business information. Each webinar continues the dialogue in the community, on topics such as customer care, supply chain, employee and financial issues, as a way of pulling together to recover from the crisis.

OIDA has also compiled a list of recommended external resources with timely information on how to navigate through the coronavirus situation. Check **www.osa.org/industry/industry_covid19/** for updates.

Thank You, Volunteers

Optical Sensors and Sensing Congress Chair: **G. Wysocki**, Princeton University, USA.

Applied Industrial Spectrosopy: **K. Bakeev**, B&W Tek LLC, USA; **S. Buckley**, Ocean Optics, Inc., USA.

Laser Applications to Chemical, Security and Environmental Analysis: **J. Kiefer**, Universität Bremen, Germany; **W. Meier**, German Aerospace Center DLR, Germany; **H. Stauffer** and **P. Hsu**, Spectral Energies LLC, USA; **F. Beyrau**, Otto von Guericke Universität Magdeburg, Germany; **J. Bood**, Lund University, Sweden.

Optical Sensors: **P. Pellegrino**, Army Research Laboratory, USA; **G. Brambilla**, University of Southampton, U.K.; **F. Vollmer**, University of Exeter, U.K.

Optics and Photonics for Sensing the Environment: **D. Killinger**, University of South Florida, USA; **R. Menzies**, USA; **I. Coddington**, NIST, USA; **J. Jágerská**, UiT The Arctic University of Norway, Norway.

Propagation Through and Characterization of Atmospheric and Oceanic Phenomena: **S. Gladysz**, Fraunhofer IOSB, Germany; **D. Voelz**, New Mexico State University, USA; **S. Basu**, Technische Universiteit Delft, Netherlands; **D. LeMaster**, U.S. Air Force Research Laboratory, USA.

Imaging and Applied Optics Congress Chair: **A. Watnik**, U.S. Naval Research Laboratory, USA.

3D Image Acquisition and Display: **H. Hua**, University of Arizona, USA; **B. Javidi**, University of Connecticut, USA; **O. Matoba**, Kobe University, Japan; **A. Stern**, Ben Gurion University of the Negev, Israel; **S. Thibault**, Université Laval, Canada.

Adaptive Optics: **J. Christou**, Large Binocular Telescope Observatory, USA; **C. Kulcsar**, Institut d'Optique Graduate School, France; **J. Girkin**, University of Durham, U.K.

Computational Optical Sensing and Imaging: **A. Ashok**, University of Arizona, USA; **M. Gehm**, Duke University, USA; **T. Alieva**, Universidad Complutense de Madrid, Spain; **J. Ke**, Beijing Institute of Technology, China; **F. Willomitzer**, Northwestern University, USA.

Digital Holography and 3D Imaging: **L. Cao**, Tsinghua University, China; **J. Liu**, Beijing Institute of Technology, China; **P. Ferraro**, Institute of Intelligent Systems CNR, Italy; **E. Stoykova**, Bulgarian Academy of Sciences, Bulgaria.

Imaging Systems and Applications: **K. Gemp**, MITRE Corp, USA; **M. Groenert**, U.S. Army RDECOM CERDEC, USA; **M. Roy**, University of New South Wales, Australia; **C. Joo**, Yonsei University, South Korea; **C. Streuber**, Raytheon Missile Systems, USA.

OSA/OIDA & OSA Partner Meetings

In light of the COVID-19 (coronavirus) pandemic, OSA is exploring all options for upcoming OSA Events. Please visit the individual meetings pages for updates.

VIRTUAL MEETINGS

(as of 13 May 2020)

www.osa.org/WeAreOn

OSA Imaging and Applied Optics Congress

22 – 26 June 2020, Pacific Daylight Time (PDT), GMT-07:00

- *3D Image Acquisition and Display: Technology, Perception and Applications (3D)*
- *Adaptive Optics: Methods, Analysis and Applications (AO)*
- *Computational Optical Sensing and Imaging (COSI)*
- *Digital Holography and Three-dimensional Imaging (DH)*
- *Imaging Systems and Applications (IS)*

www.osa.org/ImagingOPC

OSA Optical Sensors and Sensing Congress

22 – 26 June 2020, Pacific Daylight Time (PDT), GMT-07:00

- *Applied Industrial Spectroscopy (AIS)*
- *Laser Applications to Chemical, Security and Environmental Analysis (LACSEA)*
- *Optical Sensors (Sensors)*
- *Optics and Photonics for Sensing the Environment (ES)*
- *Propagation Through and Characterization of Atmospheric and Oceanic Phenomena (PcAOP)*

www.osa.org/SensingOPC

OSAF Innovation School

12 – 16 July 2020, Eastern Daylight Time (EDT), GMT-04:00

www.osa.org/Innovation

OSA Advanced Photonics Congress

13 – 16 July 2020, Eastern Daylight Time (EDT), GMT-04:00

- *Integrated Photonics Research, Silicon and Nanophotonics (IPR)*
- *Nonlinear Photonics (NP)*
- *Novel Optical Materials and Applications (NOMA)*
- *Optical Devices and Materials for Solar Energy and Solid-state Lighting (PVLED)*
- *Photonics in Switching and Computing (PSC)*
- *Photonic Networks and Devices (Networks)*
- *Signal Processing in Photonic Communications (SPPCom)*
- *Specialty Optical Fibers (SOF)*

www.osa.org/PhotonicsOPC

OSA Applied Industrial Optics Webinar Series

20 – 22 July 2020, Eastern Daylight Time (EDT), GMT-04:00

www.osa.org/AIO

AS SCHEDULED

OSAF Siegman International School on Lasers

18 – 25 July 2020, University of Warsaw, Chęciny, Poland

www.osa.org/SiegmanSchool

OSA Incubator on Visual Perception in AR/VR

23 – 25 July 2020, OSA Headquarters, Washington, DC, USA (invitation only)

www.osa.org/VisualPerceptionInc

14th Pacific Rim Conference on Lasers and Electro-Optics (CLEO-PacRim)

2 – 6 August 2020, International Convention Centre Sydney
Sydney, New South Wales, Australia

www.CLEOPR2020.org

OSA Frontiers in Optics + Laser Science APS/DLS

13 – 17 September 2020, Washington Marriott Wardman Park, Washington, DC, USA

www.FrontiersinOptics.org

Learning from Light: An OSA Incubator on Machine Learning

7 – 9 October 2020, OSA Headquarters, Washington, DC, USA (invitation only)

www.osa.org/MachineLearningInc

OSA Laser Congress

12 – 16 October 2020, Québec City Convention Centre, Québec City, Québec, Canada

- *Advanced Solid State Lasers Conference (ASSL)*
- *Laser Applications Conference (LAC)*

www.osa.org/LaserOPC

OSA 2nd Annual 5G Summit

20 – 21 October 2020, OSA Headquarters, Washington, DC, USA

www.osa.org/5g

OSA Latin America Optics and Photonics Conference (LAOP)

16 – 19 November 2020, Mar Hotel, Recife, Pernambuco, Brazil

www.osa.org/LAOP

POSTPONED

- OSA High-brightness Sources and Light-driven Interactions Congress
- OSA Quantum 2.0 Conference

CANCELLED

- OIDA Forum on Optics in Autonomy and Sensing
- OSA Applied Industrial Optics Topical Meeting

The OSA Foundation & Coherent Inc. are pleased to announce the 2020 recipient of

THE BERNARD J. COUILLAUD PRIZE

Bo Li

Cornell University, USA

Bo Li received his Ph.D. in telecommunications from Beijing Jiaotong University, China, and INRS-EMT, Canada. He is currently a postdoctoral researcher at Cornell University, USA. His recent research interests involve multi-photon laser-scanning fluorescence microscopy, femtosecond fiber laser, and telecommunications. He has more than 40 publications in top scientific journals and technical conferences, as well as many invited and post-deadline presentations at leading international conferences.

A major goal of brain research is to image the dynamics of groups of neurons during behavior. However, established methods with high spatiotemporal resolution are limited by the potential for laser damage to living tissues. He is working to develop an adaptive excitation source that only illuminates the region of interest, which leads to a 30-fold reduction in the power requirement for two or three photon microscopy, and further enables large field-of-view up to several mm2 for calcium imaging or high speed up to kHz frame rate for voltage imaging.

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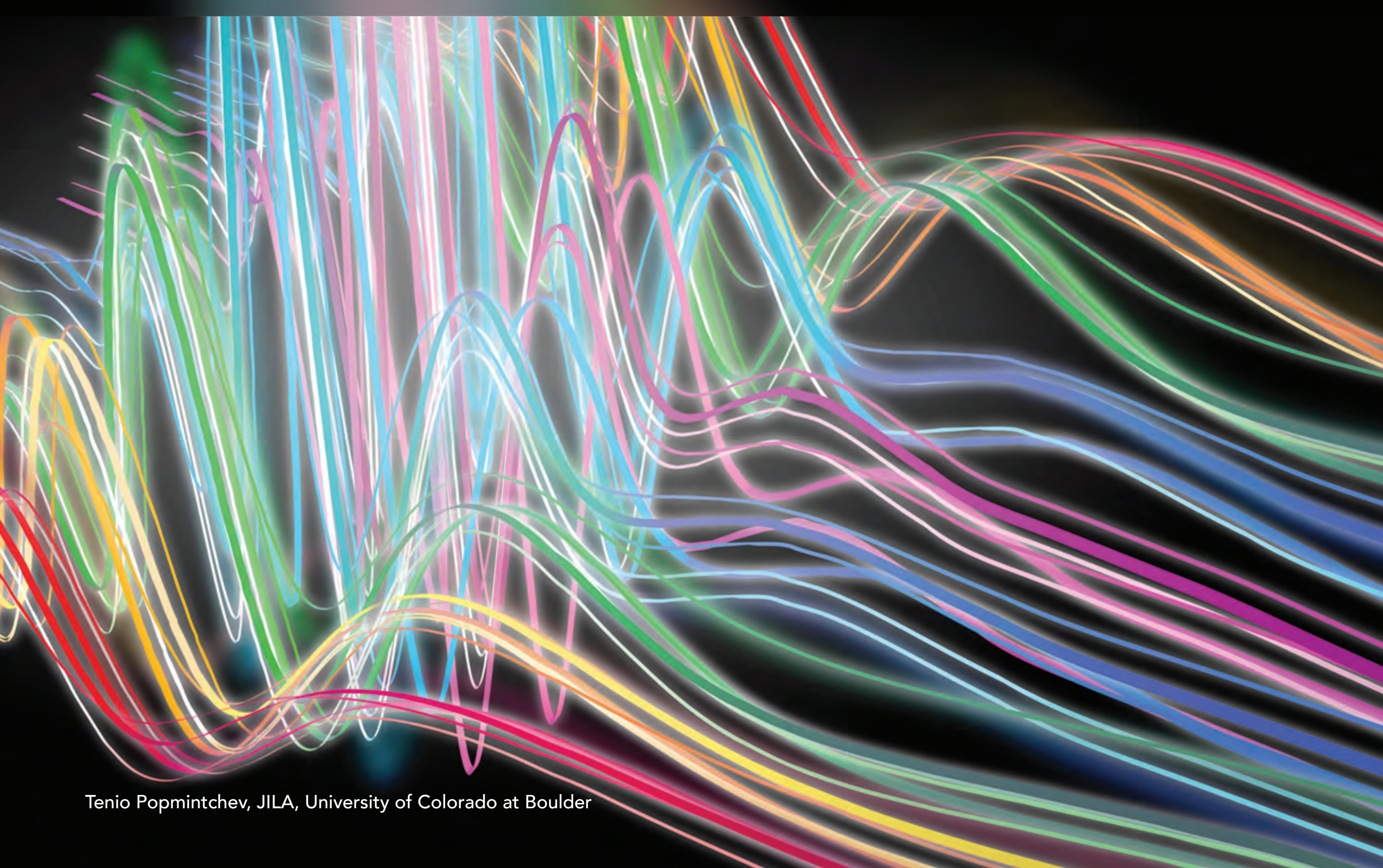
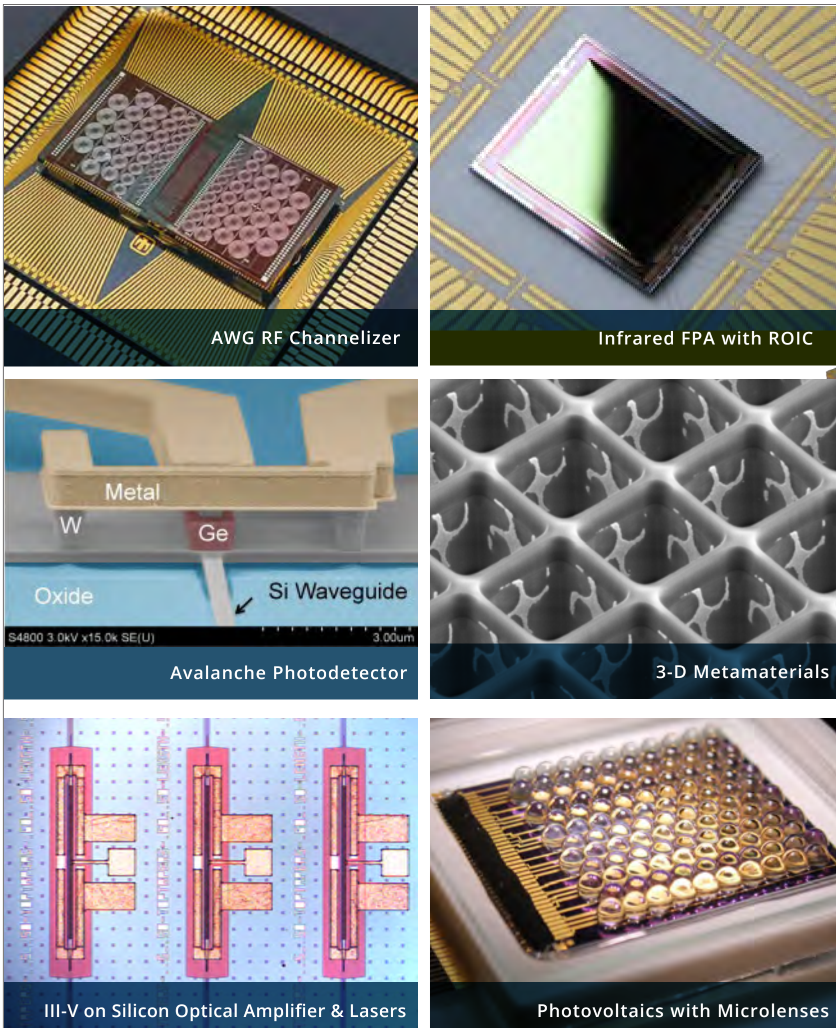


Tenio Popmintchev, JILA, University of Colorado at Boulder



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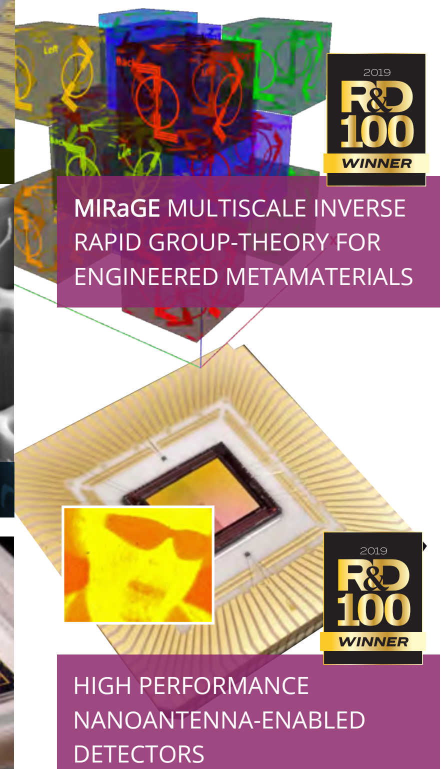

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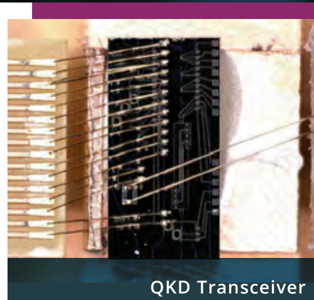

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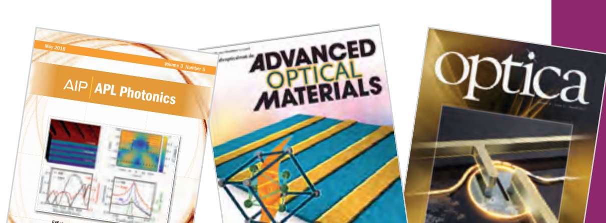

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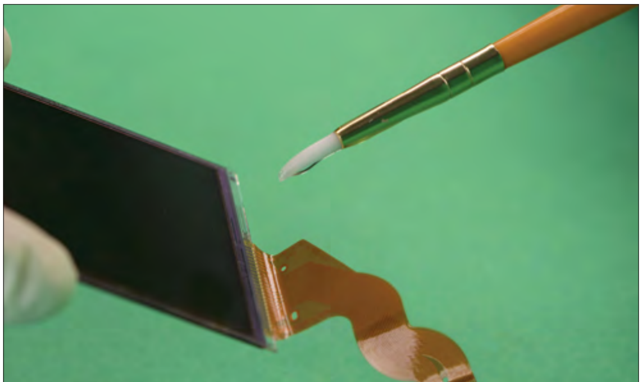

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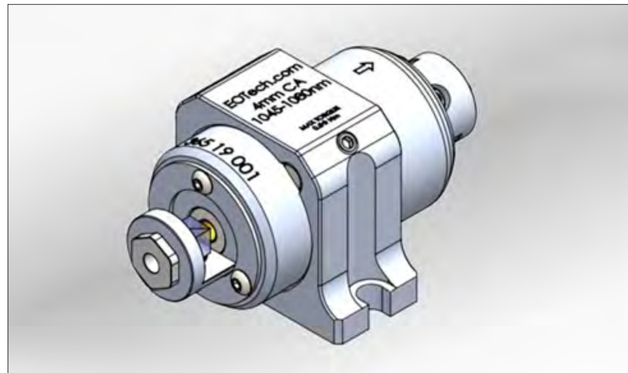

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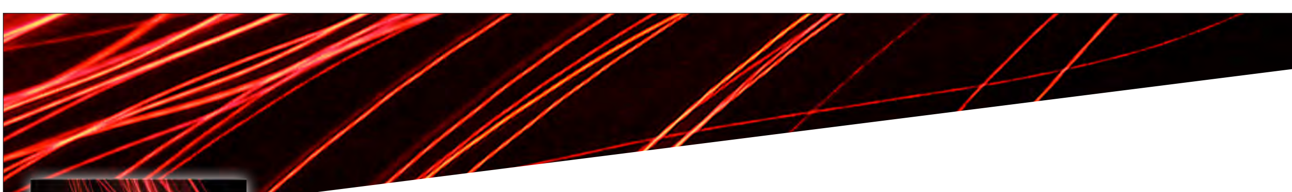

Svetlana Boriskina
Deputy Editor
Energy and Environmental Optics Express

ENERGY AND ENVIRONMENTAL OPTICS EXPRESS

A dedicated section of *Optics Express*

Optics Express (OpEx) has expanded its dedicated section on energy, now named **Energy and Environmental Optics Express** and led by Editor Svetlana Boriskina of MIT.

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After Image

Light painting orb created with an LED attached to a gyroscope. Precession is traced as the system loses energy.

— Edgar Guevara, CONACYT-UASLP, San Luis Potosí, México

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