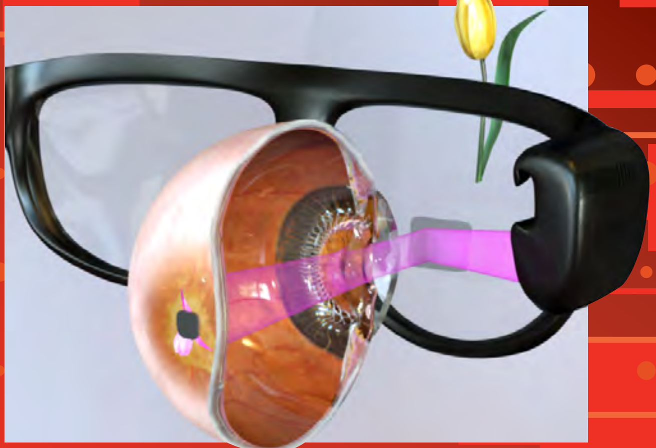
TUESDAY
EDITION

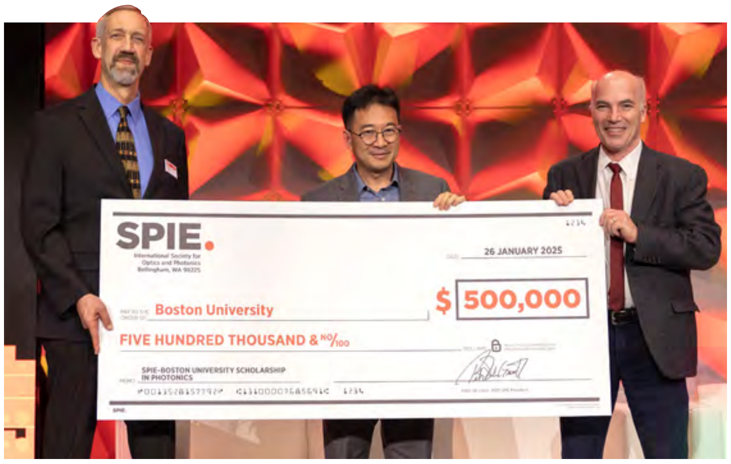
SPIE. | optics.org | TUESDAY, JANUARY 28, 2025

PHOTONICS WEST SHOW DAILY

"Bionic" retinal implants
p. 04



SPIE and Boston University announce joint $1M fund for student scholarships



2025 SPIE President Peter De Groot (left) presents Boston University's Ji-Xin Cheng (center) and Thomas Bifano (right) with $500,000. Credit: Joey Cobbs.

The new endowment will support graduate and post-doctoral students at the Boston University Photonics Center

At Sunday evening's biophotonics plenary, SPIE and Boston University (BU) announced the establishment of the SPIE-Boston University Scholarship in Photonics. The $500,000 gift from SPIE will be fully matched by the university.

Part of the SPIE Endowment Matching Program, this fund supports annual scholarships for BU students at the Boston University Photonics Center. Scholarships will be available for up to two graduate students or one postdoctoral researcher exploring impactful areas of photonics research, and will cover stipends, health benefits, and travel costs to present their work at an SPIE conference.

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Singular Photonics launches with single-photon sensors

Startup Singular Photonics has revealed itself to the world at this year's Photonics West, emerging from stealth mode with a new generation of silicon-based single-photon avalanche detectors (SPADs).

Spun out of the laboratory of University of Edinburgh professor and digital imaging pioneer Robert Henderson, Singular says it is one of the first companies to bring advanced computation to SPAD-based image sensing. Offering in-pixel and cross-pixel storage and computations at the lowest possible light levels, its products will be showcased for the first time during this year's exhibition, at booth 5017.

The company has launched two sensors, both of which are available now. They are known as "Andarta," which has been developed in collaboration with tech giant Meta, and "Sirona," a 512-pixel SPAD-based line sensor capable of time-correlated single photon counting (TCSPC).

Singular says that Andarta represents a significant step for SPAD integration in the wearables space, by enabling functions like cerebral blood flow monitoring at depths not possible with current sensors. Sirona is aimed at Raman spectroscopy, fluorescence lifetime imaging microscopy (FLIM), time-of-flight, and quantum applications.

"With on-chip histogramming and time binning capability, the

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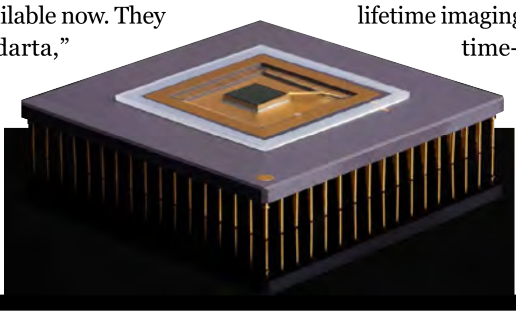

Andarta sensor. Credit: Singular Photonics.

DON'T MISS THESE EVENTS.

PHOTONICS WEST EXHIBITION
10 AM – 5 PM Moscone North/South Exhibition Halls

QUANTUM WEST EXPO
10 AM – 5 PM Moscone South, Quantum Expo (Upper Mezzanine)

JOB FAIR
10 AM – 5 PM Moscone Center, Hall C (Exhibit Level)

AR | VR | MR EXHIBITION
10 AM – 5 PM Moscone West, Level 3

ACCELERATING PHOTONICS INNOVATIONS TO THE MARKETPLACE WITH THE TECH HUBS
10:30 AM – 12:00 PM Moscone Center, Expo Stage, Hall DE (Exhibit Level)

STARTUP CHALLENGE FINALS
2:30 – 4:00 PM Moscone Center, Expo Stage, Hall DE (Exhibit Level)

LASE AND SELECT BIOS POSTER SESSION
6:00 – 8:00 PM Moscone West, Room 2003 (Level 2)

SPIE MEMBER AFTER-DINNER RECEPTION
8:00 – 9:30 PM San Francisco Museum of Modern Art (151 Third St.)

For the full schedule and most up-to-date info, download the SPIE Conferences app. Some events require a paid technical registration.

IN THIS ISSUE.

TRIOPTICS

See the Difference

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Our highlights at SPIE Photonics West booth #1640

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SPIE AR | VR | MR booth #6305

New AR waveguide testing solution for high volume production: ImageMaster® PRO AR Reflection sets new standards with widefield diffraction-limited optics for unmatched accuracy and takt times.

PRISM AWARDS FINALIST

Learn about our groundbreaking Prism Award Finalist OptiCentric® Bonding 5D MultiAlign, that enables efficient production of high-precision lenses with a compact design! Our experts are eager to share the excitement and discuss how this innovation can benefit your business.

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Panelists discuss quantum biotech's exciting future

(L-R) Moderator Halina Rubinsztein-Dunlop with panelists Miles Padgett, Warwick Bowen, Sergey Polyakov, Celia Merzbacher, and Jennifer Dionne. Credit: Joey Cobbs.

The future of quantum biotechnology was the feature of a lively panel discussion Sunday on the Expo Stage. Moderated by Halina Rubinsztein-Dunlop, University of Queensland (UQ), Australia, panelists discussed the promise of quantum biotechnologies to revolutionize understanding, for example, of the molecular origins of cystic fibrosis and Alzheimer's disease, deliver new diagnostic and imaging capabilities, and accelerate development of new medicines, materials, and industrial chemicals.

Panelists included Miles Padgett, University of Glasgow; Warwick Bowen, UQ; Sergey Polyakov, US National Institute of Standards and Technology; Celia Merzbacher, executive director of QED-C; and Jennifer Dionne, Stanford University.

Rubinsztein-Dunlop said that the "wins" of the quantum revolution, including quantum biotechnologies, are coming every day. Padgett remarked that "where quantum has got most to offer is in healthcare, whether that be better cameras, better microscopes or other kind of sensors — sensing things that you would not previously have thought of."

Bowen cautioned that revolutions in healthcare would require more than lone quantum physicists toiling in their laboratories. He said that efforts to create new quantum biotechnologies must be a multidisciplinary effort so that developers understand the needs in the life sciences. He said industry analysts believe that in terms of the value of quantum technologies, half will be in chemistry, and another half in the life sciences. "There's a real opportunity in biotechnology-related areas to secure genuine socio-economic benefit."

Polyakov suggested that life scientists should keep in mind all of the potential benefits of quantum biotechnologies, not simply exceeding the limits of classical sensors. For example, he said, quantum could offer sensing capabilities that also work around problems such as depletion of resources like helium that current technologies depend on. "Remember the reason, when it comes to applications, you don't get any brownie points for being quantum or not being quantum. You have got to solve your problem."

Merzbacher reminded the audience that further development of quantum computing would be essential to health and life sciences. Along with enthusiasm for what quantum sensing can do, pharmaceutical companies are exploring how a quantum computer could, for example, help shorten the timeline from drug discovery to clinical trials, better manage manufacturing logistics — "any processes and activities that could be optimized or improved by quantum computing."

Dionne noted that the advent of commercial artificial intelligence has brought much discussion of the huge amounts of data needed to feed large language models. However, she said, there are calculations showing a nine order of magnitude gap between all of the data zipping around on the internet today and the data biology uses to communicate within itself, for example, the structure/function relationships in protein folding. "That's where I think quantum mechanics and quantum technologies has a huge role to play in terms of opening up new data in biology to create the medicines, pharmaceuticals, and agrochemicals of tomorrow."

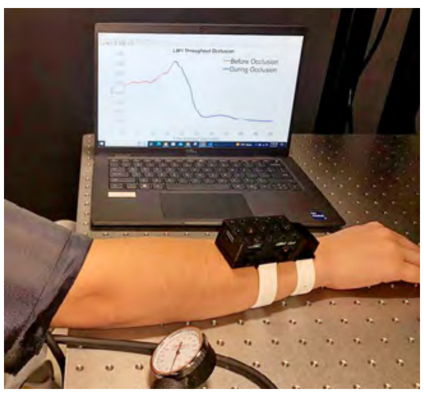
WILLIAM G. SCHULZ

Laser speckle wearable detects postpartum hemorrhage

A BiOS keynote on Saturday described a low-cost, portable laser-based device that warns of life-threatening blood loss during labor or after childbirth. This serious heavy bleeding — postpartum hemorrhage (PPH) — can be difficult to detect before it becomes an emergency, accounting for almost 30% of maternal deaths globally and just over 10% of maternal deaths in the United States.

Speaker Professor Christine M. O'Brien, of Washington University in St. Louis, said that her group's wearable laser speckle flow index (LSFI) sensors are a "promising technology for early detection of PPH in both high and low resource settings." Her work has already extended to partnerships in Kenya and Nigeria.

LSFI extracts information about blood flow by using a laser and a camera to detect and quantify spatial and temporal changes in speckle patterns formed when the light interacts with moving blood cells. O'Brien's group has developed a wireless, battery-powered laser speckle system that can be worn on the wrist. They have also developed a fast speckle processing method for onboard video data processing, removing the need for bulky and costly systems, typically priced in the tens of thousands of dollars: "We have developed an untethered, wireless, low-cost, wearable LSFI device, for about $150. The LSFI signal correlates with net fluids lost during hemorrhage."



Portable and low-cost. Credit: Washington University in St. Louis.

PPH is the leading cause of maternal mortality globally. It has also been described as "the most preventable cause of maternal mortality." The leading factors causing preventable PPH are delays in diagnosis and treatment.

She detailed her group's device thus: "Our laser speckle imaging system uses a V2 Raspberry Pi camera and a laser diode, and is controlled by a Raspberry Pi Zero computer. The device contains no consumables and is reusable and compact. The sensor has been successfully tested in a swine hemorrhage model, human blood-donor models, and in cesarean deliveries, with high correlation to net fluid [behavior]."

This progress provides a framework for a novel low-cost, noninvasive technology that identifies ongoing blood loss rapidly, with the goal of reducing the unacceptably high rates of global maternal mortality caused by hemorrhage in low- and high-resource settings alike.

"To move beyond research application to true clinical use, the device would need to be manufactured by a commercial partner creating a device that meets regulatory criteria," O'Brien said. "It would need to undergo testing under a number of conditions and with a diverse population. We are obtaining feedback and conducting tests with our prototypes, including the effects caused by motion, and its performance across a range of skin pigmentation levels to ensure the results are not biased by skin color."

MATTHEW PEACH

$1M fund

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"We are enormously grateful for the opportunity to partner with SPIE in this endowment program to support graduate and post-graduate research scholarship at the frontiers of optics and photonics," said Photonics Center Director and Vice President and Associate Provost *ad interim* for Research Dr. Thomas Bifano.

"The Boston University Photonics Center has a long and proud history of collaboration with SPIE, including the sponsorship of SPIE events and an SPIE student chapter. Creation of this endowed fund will advance our shared commitment with SPIE to help train and support future leaders in the societally important fields of optics and photonics."

"The SPIE-Boston University Scholarship in Photonics offers critical support for the future of photonics," said SPIE CEO Kent Rochford.

"By supporting the education of photonics researchers as well as potential photonics industry leaders, the SPIE-Boston University Scholarship in Photonics will have an ongoing impact on the field for generations to come, and we are delighted to partner with the university on this enterprising venture," he added.

The SPIE Endowment Matching Program was established in 2019. With this latest gift — its 12th major gift — SPIE has provided over $4.5 million in matching gifts, resulting in more than $12 million in dedicated funds.

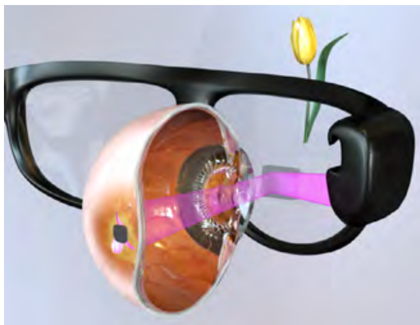
The SPIE Endowment Matching Program supports optics and photonics education and the future of the industry by partnering with college, institute, and university programs with optics and photonics degrees, or with other disciplines allied to the SPIE mission.

DANEET STEFFENS

Retinal implants primed for resolution upgrade

Vision-impaired people with 'bionic' retinal implants that allow them to see basic images and shapes could have their sight further upgraded, thanks to the latest developments in photovoltaic prostheses at Stanford University.

Based on technology pioneered by Daniel Palanker's research group, a first generation of implants has already restored a form of vision to dozens of advanced macular degeneration (AMD) patients involved in two clinical trials. Used in combination with AR-style glasses that beam an image to the implant via an infrared emitter, those "PRIMA" implants have shown good stability four years after being implanted in five people who took part in an initial clinical trial in France.



PRIMA system design. Credit: Pixium Vision.

Presenting during Saturday's Ophthalmic Technologies conference, Mohajeet Bhuckory from Palanker's group said that it now looked possible to replace the original implants with upgraded versions featuring smaller pixel sizes.

Bhuckory explained that the current generation of PRIMA implants, which use 100 micron-sized pixels, could be upgraded with devices featuring 20 micron pixels. In tests on rats, the team removed the older implants and replaced them with the upgraded technology.

The research team believes that in humans such an upgrade could in fact be easier to perform than in rats, because there is a larger cavity in the eye in which to fit the implant.

"These results support the feasibility of upgrading the subretinal implant in-situ to improve prosthetic vision, potentially with acuity exceeding 20/100," reported Bhuckory, who was one of five finalists shortlisted in this year's Pascal Rol Award for the best paper in the Ophthalmic Technologies conference. The 20/100 figure would represent a huge improvement on the visual acuity of 20/420 possible with the existing generation of implants.

In a separate talk on Sunday, Palanker himself described the 20-year effort to develop the implants, and indicated that it could be possible for the new technology to deliver visual acuity of 20/80 or even 20/40 in humans.

Showing videos of implanted patients now capable of reading books, writing numbers, and seeing the names of station stops on a map at a Paris metro station, he said that vision in some patients had even improved after a 12-month follow-up, hinting at the positive effect of brain plasticity.

MIKE HATCHER

CREAL display for lifelike AR view

Swiss startup CREAL's new light field display, called Clarity, specified for augmented reality (AR) glasses, is now ready for integration. By replicating real-world light to deliver genuine focus depth, the display provides 3D perception for a "natural, comfortable, and healthy visual experience in AR," the company states.

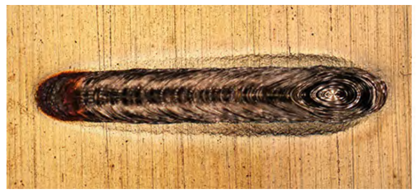
The display, which is this week being demonstrated on booth 6406 at SPIE AR | VR | MR, is compatible with conventional prescription lenses, offering precise vision correction while maintaining high transparency to ensure clear view, eye contact, and social comfort.

CREAL Clarity light field display is now available for integration into AR glasses. Credit: Creal.

CREAL — whose technical team is drawn from projects at Intel, Magic Leap, EPFL, and CERN — claims that "current AR displays fall short of delivering a natural visual experience due to missing depth cues. They provide incomplete 3D by displaying flat images at a fixed focus distance — preventing our eyes from focusing at different distances as they do in reality."

Tomas Sluka, CREAL's CEO, said, "AR glasses are the next evolutionary stage of traditional eyewear. This is why we have pioneered a light field display technology that incorporates vision care requirements and traditional features."

MATTHEW PEACH



Hybrid processing for 4mm-thick copper using the 5kW blue laser (left: top view; right: cross-section view). Credit: Furukawa Electric.

5 kW blue laser and NIR fiber laser hybrid speeds clean copper processing

With the recent acceleration of the shift toward electric vehicles, the need for more sophisticated copper material processing is rapidly increasing, meaning improved laser processing techniques are essential.

High power near-infrared (NIR) fiber lasers are widely used in laser processing of metals because of their high electric-optical conversion efficiency and excellent beam quality. However, copper welding using NIR fiber lasers is difficult because copper has low absorption in the NIR range and high thermal conductivity, which causes rapid heat diffusion at the welding point.

Sunday's High-Power Diode Laser Technology XXIII conference heard two presentations from Japan-based technology companies, Nichia and Furukawa Electric, about their recent respective developments of blue laser diodes, which have been integrated with infrared sources to achieve higher powers at shorter wavelengths – and thus improved results for processing copper.

Furukawa's Sumika Sano. Credit: Matthew Peach

Presenter Sumika Sano, of Furukawa, works in the company's industrial laser system department. Her current research focus is blue and IR laser systems for copper welding. A notable highlight of her talk was a new blue laser diode module jointly developed jointly with Nichia yielding 800 W.

This, in turn, has enabled a new 5 kW blue laser that "delivers the world's highest level of brightness from optical fiber," said Sano. Considering the application of this laser to copper processing, she added, "The high-power blue laser reduces the welding time for thick copper by two-thirds, and for magnet wire processing for motors by 20%."

Furukawa Electric and Nichia jointly developed a blue laser diode module (LDM) with an output of 800 W, which is more than 1.5 times higher than conventional sources. By incorporating this blue LDM into a laser processing system, Furukawa has achieved an output of 5 kW.

Sano concluded her presentation with the news that Furukawa has expanded the commercial line-up of its "Brace" ranges of lasers, introducing the BR 5000 and the BR 0700. The BR 5000 enables more than 1.5 mm of penetration in copper plate and the continuous transition to a keyhole shape. A hybrid system of a blue 3 kW laser and NIR 6 kW laser achieves 3.5 mm penetration of copper plate – without spatter.

MATTHEW PEACH

Singular

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sensor could revolutionize spectroscopy applications," the firm said.

CEO Shahida Imani added: "We are in a unique position where we already have commercially available products and are generating revenue in our first year of incorporation. With new sensors coming to market in 2025, we are well positioned to lead the SPAD-driven imaging revolution."

Henderson, who leads Edinburgh's CMOS Sensors and Systems research group, designed one of the first SPAD image sensors in CMOS technologies in 2005, leading to the first time-of-flight sensors in 2013. They are widely used in smartphones, enabling the autofocus-assist feature.

"SPAD sensors are the future of digital imaging, but their use to date in commercial devices hasn't extended much beyond time-resolved counting of photons," remarked Henderson. "Computational cleverness can be the difference. We are building next-generation imaging sensors, where the computation is done digitally at the pixel level — exactly where the photons arrive."

MIKE HATCHER

Photonics West is your community

For us at SPIE, like many of you, the months leading up to Photonics West are filled with preparation and excitement for the week. We start our planning over a year in advance because the task is enormous. Throughout that time, I can always find motivation from the community at Photonics West and the joy that comes when you bring such a brilliant, talented, and fun group of engineers, researchers, students, and businesspeople together.

Of course, Photonics West is about sharing research, learning about the latest advancements, and experiencing the newest products. However, what truly makes it a can't miss event every year is the people and community that attend.


Dr. Kent Rochford is CEO and Executive Director of SPIE. Credit: SPIE.

Of course, Photonics West is about sharing research, learning about the latest advancements, and experiencing the newest products. However, what truly makes it a can't miss event every year is the people and community that attend.

Hopefully, you were able to attend and enjoy last night's Welcome Reception and experience the *Greatest Photonics Show on Earth*. We always enjoy seeing everyone's faces as they walk into the reception and are greeted by the year's theme, but the real entertainment for me is seeing colleagues, friends, and new acquaintances exchanging greetings or sharing a laugh as they enjoy the reception together.

We'll host our Member Reception tonight, and this event will celebrate a special milestone - SPIE is now 25,000 Members strong! It's a significant milestone for SPIE, but what's more inspiring is the impact those 25,000 people will have on the lives of others through research advancements, technology development, and outreach efforts. Being a Member of SPIE is something to be proud of — you're connected to an inspiring and collaborative group of individuals. If you are an SPIE Member, I'd love to see you at tonight's celebration. It will be a great time, and we at SPIE want to say thanks for supporting our mission in person!

A large part of that mission is community support. If you were at the Biophotonics or OPTO plenaries over the weekend, you would have seen us announce our newest endowment partners, Boston University and the National University of Singapore. Both programs will receive 500,000 dollars from SPIE to be matched by the respective universities for a total endowment of $ 1 million for each school. The annual Endowment Matching program is in addition to all of our scholarships, grants, event travel, and other forms of community support, which are part of SPIE's operating budget and not from a separate foundation; by supporting SPIE, you are supporting your community.

Today, the exhibition opens, and over 1300 companies are ready to talk to you about your lab, product, or research needs. I got a sneak peek while companies were setting up their booths, and all I can say is to be prepared for hundreds of technological innovations and some creative booth displays. The photonics industry continually inspires me, and I have no doubt that Photonics West will kick off a great 2025 for the companies exhibiting this year.

In addition to Photonics West, be sure to head over to Moscone West for AR|VR|MR to see the latest in XR headsets and glasses, as well as the myriad of cutting-edge components that make this industry possible. In the past few years, optics and photonics have been making huge strides toward solving the technical hurdles for these companies. Also, a can't miss is the museum of AR and VR goggles, where over 100 headsets are on display to give you a look at how far the technology has come.

While the tradeshow floors are the place to get a firsthand appreciation of our industry, at yesterday's SPIE Global Business Forum, we heard from market experts on the economic impact photonics has and the strength it gains from its diverse applications and end markets it enables. At the event, we released our industry report, which shows that since 2012, the photonics components industry has grown at a rate of almost twice that of global GDP over the same period. Furthermore, the production of core optics and photonics components employs more than 1.3 million people worldwide. Simply put, our industry is strong and vital to the global economy.

So whether this is your first Photonics West or your 30th, take time to appreciate what you are a part of. Your work contributes to our success as a community and industry while also furthering the engineering and scientific enterprise that underpins so much of our daily lives and will help solve our most significant global challenges. Now look around; the conference rooms, exhibit halls, and coffee breaks are full of people like you — your Photonics West community. Make sure you take advantage of the people surrounding you this week. Reconnect with old friends, make new connections, and find potential collaborators. Nearly every career success story I hear from leaders in our field includes a serendipitous conversation or meeting at a conference that opened an unforeseen opportunity and unexpected accomplishment. Here's to Photonics West 2025 giving you your unplanned connection that leads to your next success.

KENT ROCHFORD


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Quantum inspiration

As Sir Peter Knight explains, the International Year of Quantum offers myriad opportunities to embrace the latest photonics-enabled technology.

In the annals of quantum, 2025 will be momentous. Not only does it mark the 100th anniversary of quantum mechanics, 2025 will be celebrated on a global scale as the UNESCO-designated International Year of Quantum Science and Technology (IYQ). "The 100th anniversary was a good tie-in," acknowledges Sir Peter Knight, who co-chairs the IYQ steering committee. "But it was quite timely to do it anyway, because right around the world, there's been advances in the application of quantum. We are looking back over a century of tremendous technological change that has been enabled by it."

Sir Peter Knight. Credit: University of Durham.

As a leading researcher and advocate of physics, photonics, and quantum optics for four decades, Knight knows that of which he speaks. A former professor at Imperial College London who was also chief scientist at the UK's National Physical Laboratory (NPL), Knight remains involved with NPL efforts as well as advising the UK government. Even better, his enthusiasm for quantum, its critical applications — present and future — and its committed proponents, is catching. "The founders of quantum mechanics showed us our ability to have a quantitative understanding of matter at the atomic level," he explains. "We could suddenly understand what was going on at this really microscopic level, and it meant that we could exploit that understanding in ways we couldn't have explained or utilized through classical physics. Semiconductors, superconductors, lasers — all of that came from that first quantum revolution."

The second quantum revolution, playing out now, harnessed concepts and thought experiments such as Schrodinger's Cat, applying their practical implications. "People were starting to understand ways in which we could manipulate — at the atomic scale — these funny sort of quantum superpositions," says Knight, though it's taking time to catch up with a wider audience. "When I talk to a non-physics community and say, 'Okay, who used quantum coherence today?" nobody's hands go up. Then I say, 'Actually, you all did, because that's how GPS works — your Sat Nav works because the GPS system runs off atomic clocks. And the way that atomic clocks work is that we can put the atoms in the atomic clock into a superposition of being in two states at the same time.'"

Those position, navigation, and timing elements were the first big indication that we could use quantum at such a level, notes Knight. "Most of the time, people think I'm going to be talking about quantum computing, but there's a lot more to quantum than that: there is sensing and imaging and communications," he says. "GPS is just one wonderful example, and it's already part of our daily lives."

Those same atomic magnets that process and form atomic clocks are having a life-changing impact in healthcare. Miniature versions of such magnets are so sensitive that they can detect the magnetic field caused by brain-neuron firings, a capability which translates into functional, non-invasive brain imaging. "We already do this with a MEG — a magnetoencephalography — machine. But for a child, that's terrifying. They have to go into these superconducting tunnels and be absolutely still for ages. Using quantum sensors, we can put the sensor into headgear similar to a cycle helmet and the child can just run around! Who'd have thought that using the tiny atomic magnets processing our clocks, photonic clocks, we can actually do brain imaging!?"

Governments, of course, are interested in the cryptographic significance of quantum computers. While machines of sufficient size and capability are about a decade away, Knight emphasizes the importance of public-private partnerships when it comes to developing quantum technology. "Talking to the investor community is really important, as is engaging with industry," says Knight, "And I work with a lot of startups. But with hardware-based technology, you need to be patient; there's a lot of discussion around patient capital. One of the things we'll see at Photonics West and Quantum West is a meeting of the communities that are going to come together; a lot of what we do can only be done in an international environment. I'm on a panel at Quantum West with John Burke, for example. John is a good friend from the US Department of Defense, and we talk a *lot* about how there's a mutual advantage by working together. People often say, 'Leave it to the market.' But look at Apple and the iPhone: an awful lot what goes into an iPhone was a 10-year investment by DARPA. It's that public-private partnership that has to be sustained with the right sort of dialogue. The International Year of Quantum is going to enable us to really get that dialogue going across a whole raft of stakeholders."

Photonics West is a fitting place to start a year so focused on quantum. "In the most successful of our quantum platforms, both in sensing and imaging and also in quantum computing, the engines are photonic engines," says Knight. "The driver of innovation in this space is going to be the photonics industry. I was able to build a fairly successful coordinated program in the UK, because not only did we have great science going on, but we had a photonics industry. Photonics is a hidden gem in the world economy, and a key enabler of innovation in quantum."

Knight is also angling for an IYQ outcome that looks to the future in another way: "I hope we can inspire a whole generation of young people. It's a complicated business we're in, but it's enormous fun and it's great to have a career in it. And *none* of this is going to be possible without committed, bright young people coming into the field and proving me wrong and do something completely different and really exciting."

IYQ offers a great opportunity to reach those future quantum engineers, as does Photonics West, where Knight plans to do quite a bit of networking. "I sort of run a dating agency for quantum," he grins cheekily. "I put this person together with that person, and I plan on using the whole year getting people to realize that, together, we can do stuff we can't do separately."

DANEET STEFFENS

Photonic quantum technologies going mainstream

OPTO Plenary speaker Christine Silberhorn offers a glimpse into a future where photonic quantum technologies take on an increasingly important role in science and society.

To those outside the field, a laser is a large piece of laboratory equipment. It is not a photonic structure so small it is invisible to the naked eye. Yet today, thanks to sophisticated nanofabrication techniques, miniaturized versions of lasers, waveguides, detectors, and many more optical structures are not only achievable but becoming reasonably commonplace.

They form the foundations for developing novel photonics quantum systems and quantum technological applications, some of which are already available today. For example, over a decade ago, the first commercially available quantum key distribution systems, encoding information in photons for more secure communications, were released. And numerous quantum photonic sensors have been developed, including optically pumped magnetometers to precisely measure extremely weak magnetic fields, for medical imaging, geological exploration, and navigation systems. More recently, companies such as Xanadu Quantum Technologies and ORCA Computing have been attempting to develop and commercialize practical photonic quantum computers.

However, it is universally acknowledged that science and industry have only scratched the surface of what is possible with photonic quantum technologies so far. Integrating miniaturized optical components onto chips in a scalable way will deliver sophisticated and complex photonic integrated circuits (PICs) that have the potential to unlock a plethora of benefits, including enhanced performance, reduced footprint, and lower power consumption, and most importantly enabling transformative quantum technology applications that are envisioned to bring countless benefits to existing and new fields of application, and transform a host of industries.

This is why Christine Silberhorn's OPTO Plenary, "Photonic quantum technologies: from integrated quantum devices to designing scalable complex systems" was so captivating. "People have integrated optics for some systems," says Silberhorn. "But you are standing on the shoulders of giants: it's challenging because you need extremely high-quality devices, and you have to bring together a lot of different quantum know-how and ideas, and tailor and develop them in other parameter spaces."

Christine Silberhorn (left) with a student in the quantum optics laboratory, April 2023. Credit: Paderborn University, Besim Mazhiqi.

Silberhorn is full professor at Paderborn University, Germany. She has made significant contributions to the field of fundamental quantum photonics, conducting the world's first experimental demonstration of entangled states in the wave property of light (quantum correlations) and the simultaneous existence of the wave and particle nature of nonclassical correlations, known as Einstein–Podolsky–Rosen states. At the same time, for many years she has been attempting to develop practical and scalable integrated photonic systems, attacking the problem from three complementary directions.

Her foundational research focus is engineering integrated devices made of synthetic crystalline material, lithium niobate. This material has favorable ferroelectric, electro-optic, and acousto-optic properties, making it ideal as a basis for low-loss integrated linear and nonlinear quantum photonics.

Silberhorn's team combines active optical elements, such as frequency converters, and electro- and acousto-optical devices, with passive elements, like directional couplers, tapers, beam splitters, junctions, etc, to deliver nonlinear optical waveguide lithium niobate substrates that act as a platform for many of the Paderborn researchers' quantum photonics experiments.

From this basis, the second research direction involves pumping these lithium niobate systems with pulsed light. "Pumping our systems brings ultrafast optics and integrated devices in quantum optics together," Silberhorn explains. "This has consequences particularly for parametric down-conversion sources which are the workhorse of these systems."

Parametric down-conversion is a nonlinear optical process that converts a photon from a pulsed light source into a pair of photons of lower energy, allowing the generation of single photons or entangled photon pairs. Already, the team has harnessed parametric down-conversion to engineer integrated heralded single-photon sources and integrated entangled photon pair sources.

continued on page 13


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Silberhorn continued from page 11

Successful Hong-Ou-Mandel experiment

They have also created a number of other innovative integrated lithium niobate devices based on pumping their systems with pulsed light. One of their biggest breakthroughs in this direction occurred in 2019, when Silberhorn's team demonstrated the Hong–Ou–Mandel experiment on a single integrated photonic chip. The Hong–Ou–Mandel effect is an important physical mechanism to realize logic gates in optical quantum computing, where perfect interference between two photons entering a beamsplitter results in them having a 50:50 chance of exiting together in either output mode. Silberhorn's team demonstrated the effect by integrating quantum photonics components on a single chip capable of creating, bunching, and detecting two individual photons.

Silberhorn's third and final research direction is more forward-looking and aspirational, aiming to build large, complex, and advanced lithium niobate quantum PICs. More specifically, her team is attempting to realize application-specific integrated quantum circuits by bringing together nonlinear parametric down-conversion sources, passive routing elements — such as beam couplers, splitters, and switches — and actively controllable electro-optic components — like phase-modulators and polarization convertors — on a common substrate.

One of these applications could be multiphoton entanglement generation. Such multi-photon entangled quantum states are key to advancing quantum technologies such as multiparty quantum communications, quantum sensing, quantum metrology, and quantum computation.

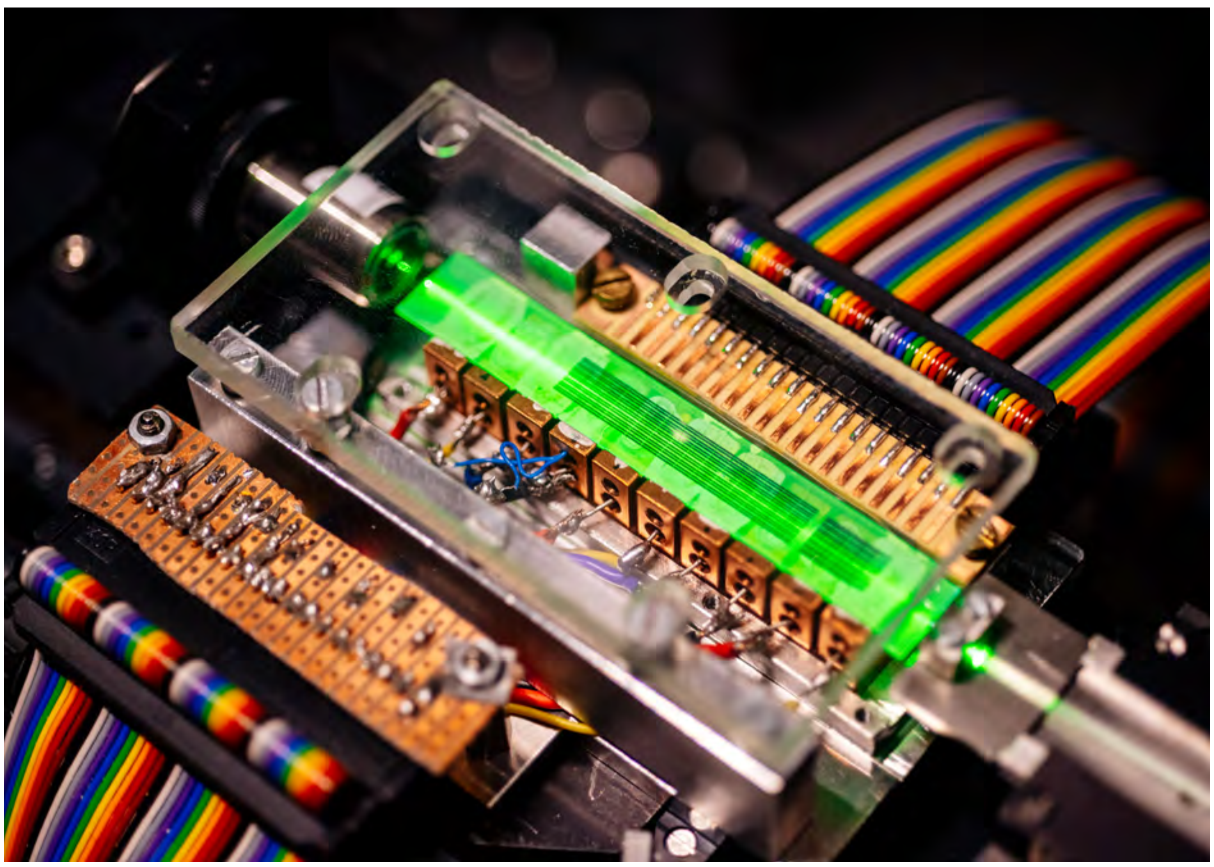
In 2022, Silberhorn's team presented research that demonstrated a method that generates entanglement between many photons with a much higher probability than previously available methods. They used a single source that generates pairs of polarization-entangled photons in succession. One photon from the first pair was stored until one photon from a subsequent pair was interfered with it. The process continued until the desired multiphoton state was reached. In their experiment, Silberhorn and collaborators fabricated four-photon and six-photon entangled states with success rates nine and 35 times better, respectively, than achieved before. But in principle, the technique can be wielded to deliver even higher multiphoton states.

Though an impressive achievement, the experimental setup for attaining these multiphoton states was large and highly complex. Shrinking this setup on a quantum PIC is not possible today. However, it is the type of application that Silberhorn believes can be achieved one day through a multidisciplinary collaborative approach; one she is employing in her role as spokesperson and founder of the Institute for Photonic Quantum Systems (PhoQS), a home for interdisciplinary research concerned with modelling and developing hardware and software for advanced quantum photonics devices.

"We will see more and more complex systems that will become much more integrated on small-scale chips and where photonics is essential in quantum communication, quantum computation, and quantum metrology," predicts Silberhorn. "But to really bring the fundamental ideas that we have onto one platform, we need a modern approach to quantum photonics where we bring different expertise together from fundamental physics, quantum information science, computer science, mathematics, electrical engineering, etc."

This is precisely why Silberhorn is excited to be not only presenting her research but also simply attending Photonics West (for the first time) this year. "I think Photonics West is a great gathering of a lot of different expertise where you can learn a lot, be it from nanophotonics, ultra-fast lasers, or perhaps a little bit of quantum," she enthuses. "Because I think that's where real research happens, where you bring together different fields."

BEN SKUSE



Hong-Ou-Mandel-on-a-Chip Sample. Credit: Paderborn University, Besim Mazhiqi.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Novel OptoGPCRs open new avenues in optogenetic modulation

Sunday's Neurotechnology Plenary detailed how optical technologies can lower invasiveness and improve effectiveness in treating neurological disorders such as Alzheimer's, epilepsy, and migraines.

Ofer Yizhar. Credit: Ronen Goldman.

Ofer Yizhar (left) and PhD student Daniel Zelmanoff in safety goggles as they work on a new approach for deep-brain light targeting. Credit: Ofer Yizhar.

Anyone who has ever suffered a migraine or a cluster headache almost certainly recalls wondering, amid an excruciating episode, why the pain can't just stop. One of Sunday's Neurotechnology plenary speakers, Dr. Ofer Yizhar, believes that by literally shining some light on the subject, it can.

Yizhar presented in the afternoon's Neurotechnology session, where, like Dr. Daniel Razansky of the University of Zurich in a separate talk, he described methods that could dramatically reduce invasiveness and side effects of brain procedures. Between them, they hold promise for treating a wide range of conditions.

Dr. Yizhar is working on an optical technology that projects red wavelengths to dampen hyperactive brain neurons associated with pain and other conditions, such as epilepsy. The light induces those neurons to shut down, thus halting the pain, or the seizure. It is a novel approach to optogenetics — the discipline of combining photonics with gene modification.

In conventional optogenetics used for other purposes, blue wavelengths trigger ions to travel along channels in a neural network. This flow persists for as long as the light shines on the neuron. But once the light is switched off, this ionic current ceases.

Yizhar, a professor of brain sciences at the Weizmann Institute of Science in Rehovot, Israel near Tel Aviv, is not using blue light. Nor is he using the on/off channel-based method, as he explained in his talk, "High-sensitivity optogenetic silencing with novel OptoGPCRs."

Instead, he is aiming red light at genetically modified neurons that, when stimulated only once by the light, reduces their signals. That's because the genetic portion of his optogenetics modifies the neurons with an optically sensitive protein type known as a GPCR, which stands for G-protein-coupled receptors. By their nature, optoGPCRs, when stimulated by light, do not activate conventional ion channels. Rather, they trigger the activity of what's known as G protein pathways. Yizhar's GPCRs are also known as opsins.

Like an on-off switch

"The channel-based optogenetic tools are like an on/off switch," says Yizhar. "You have light, it switches on. With no light, it switches off. Whereas with the GPCR pathway, the light kind of activates the process, and the process keeps going even after the light is switched off. It basically keeps going for a longer time in the dark."

This might sound like a way to stimulate a neuron, and it well could be. But in Yizhar's case, he is using the technology to deactivate neurons that are hyperactive, leading to aberrant brain activity.

"Turning on neurons is relatively easy," notes Yizhar, who points out that electrodes attached to the brain will do the trick. "Causing neurons to stop spiking is a much more difficult process."

Among the challenges of using conventional, channel-based optogenetics for shutdowns: "If you want to shut everything off, then you need to constantly deliver the light into the brain," Yizhar says. "If your opsin is like a channel — if it kind of closes when the light goes out — then you need the light to be always on. The reason why these GPCR pathways are useful is because they keep cycling, even after you shut down the light. So you can have a long lasting effect without having to pump so much light into the tissue."

But what would be so wrong with constantly pumping light into the brain?

"It causes all kinds of artifact — heating, damage, photoxicity, all kinds of things that we don't like to have," explains Yizhar. To pick up on one of those undesirables: photoxicity is basically a chipping away of the brain instigated by neurons absorbing photons.

Yizhar adds that the amount of light required for his G protein pathway approach compared to the "channel" method is "about four orders of magnitude less, so 10,000 fold less light."

While the G protein method is new, it is not the only innovative aspect that Yizhar is deploying to minimize the amount of light. His use of red wavelengths rather than blue also plays a big role.

The comparatively longer wavelength of red "heats the brain tissue less than the shorter wavelengths do," say Yizhar. "And it travels better through the tissue. One red photon will travel about 10 times more through the brain tissue than a blue photon before it's absorbed or scattered. The interface with biological tissue is much better with red light."

To facilitate red, Yizhar — again, on the genetic side of the optogenetic tandem — is infecting neurons with the red sensitive OPN3 gene from a mosquito. Earlier blue methods infect neurons with a blue sensitive gene derived from algae.

The OPN3 gene will sit in the neuron doing nothing, until red light springs it into action.

Yizhar's technology holds great promise for treating brain disorders linked with hyperactivity of neurons, including epilepsy, movement anomalies, and pain.

"Most of the disorders of the brain are disorders of hyperactivity, and for many of them we have no effective therapy" says Yizhar. "So this is why having an efficient inhibitory optogenetic tool that can shut down processes when they're happening in an unwanted way is really useful."

Yizhar and his team began developing the technology at Weizmann in 2016, and have proven its effectiveness in mice. One of the remaining challenges is to scale up the process so that it works reliably on larger brains, such as a human's.

A breakthrough in that direction came in 2023, when Yizhar and his team collaborated with the Rochester, MN-based Mayo Clinic to halt a seizure in a pig, which had been induced under anesthesia.

"There's a strong proof of concept," says Yizhar, who foresees further advances in his research leading to regulatory approval within the next decade.

In 2022, he co-founded a startup, Modulight.bio, at first based in Israel, and now in Boston, to eventually commercialize the technology as a treatment for neurological conditions, in some cases replacing ineffective medications, and in others providing relief where none exists today. Modulight's partners include Mayo Clinic, among others.

"The primary challenge in treating these disorders stems from a lack of precision therapies that target only the affected neurons and pathways," Modulight.bio states on its website. "Consequently, millions of patients are overtreated with therapies that have broad and often negative effects on brain function. At Modulight.bio, we are pioneering a revolutionary optogenetic therapeutic platform for severe neurological disorders that restores balance to the brain by precisely targeting pathological activity when and where it occurs."

In a similar vein of using precision procedures that minimize damage, Dr. Razansky described his work with both optical and acoustic technologies aimed at developing "more efficient and less intrusive ways to alter and observe brain activity."

Razansky holds dual positions, one as full professor of biomedical imaging at the Faculty of Medicine at the University of Zurich, and the other as full professor at the Department of Information Technologies and Electrical Engineering, ETH Zurich.

In his talk "Combining light and sound for scalable brain interrogation and stimulation," he outlined improvements in methods both for interrogating the brain and for modulating neural activity. For those who talk the talk: he touched on neuroimaging techniques including functional optoacoustic neuro-tomography for whole-brain imaging, localization optoacoustic tomography, large-field multifocal illumination microscopy, and super-resolution fluorescence localization imaging.

Razansky's research has implications in treatment of a range of neurological and neurodegenerative diseases and afflictions including Parkinson's, Alzheimer's and strokes.

MARK HALPER

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Welcome to the optics.org Product Focus which we have published specifically for Photonics West 2025 in partnership with SPIE and the Photonics West Show Daily.

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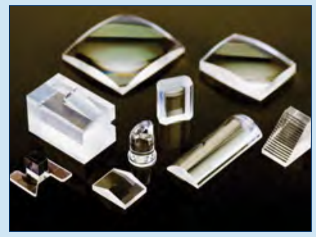

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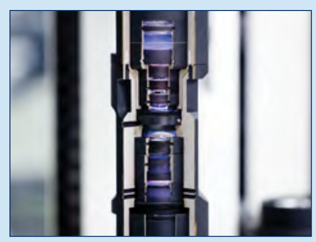

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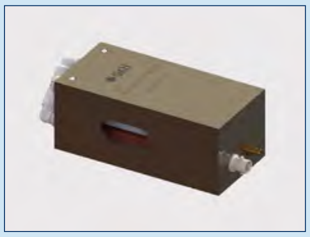

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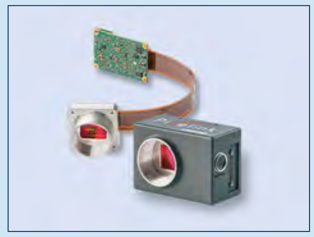

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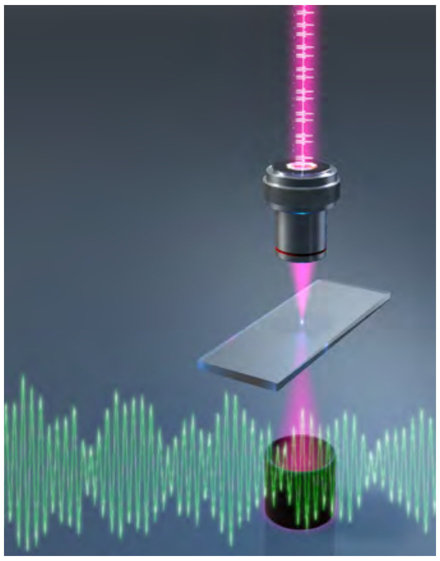
Why two frequency combs can be better than one

In her LASE Plenary, Nathalie Picqué set out the many benefits to diverse scientific fields of dual-comb interferometry, a technique she pioneered.

Originally developed to count the cycles from optical atomic clocks, the optical frequency comb has completely revolutionized the field of optical metrology since its earliest realizations in the late 1990s by the likes of John Hall and Theodor Hänsch; two of three co-recipients



Dual-comb coherent Raman spectroscopy enables hyperspectral imaging and micro-spectroscopy of fundamental transtions. Credit: Max Planck Institute of Quantum Optics.

of the 2005 Nobel Prize in Physics. The simplest frequency comb consists of a phase-stabilized single mode-locked laser that produces a series of short (femtosecond) pulses with a very precise delay between them. The spectrum of these pulses looks like the teeth of a comb or the marks of a ruler, with sharp spikes of different colors — potentially ranging from the ultraviolet into the mid-infrared spectral region — at precise, evenly spaced intervals.

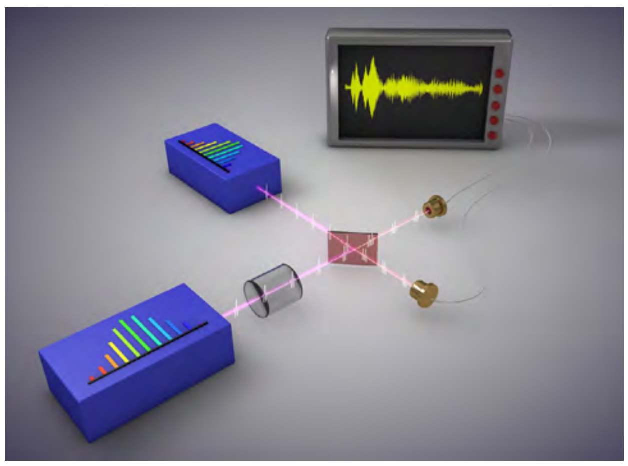
“The frequency comb made it possible to measure the absolute frequency of any light source in the optical domain, which previously was not possible,” explains Nathalie Picqué, a pioneering French physicist who has been developing frequency combs for over 20 years. “In doing this, the frequency comb was used as a frequency ruler.”

Soon, other applications besides precision optical metrology were being explored, ranging from exoplanet searches to ultra-low noise microwave generation. Picqué — who has collaborated extensively with Hänsch and is currently working both as Director of the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI), and as Professor of Physics at Humboldt University, in Berlin, Germany — was and remains at the vanguard of this application revolution.

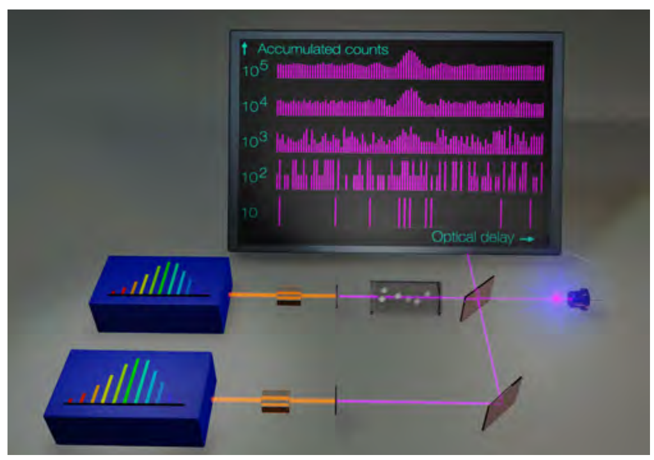
“I thought, instead of using the comb as a frequency ruler, which does not interact with the sample you would like to analyze, why not use it as a light source that directly interacts with the sample?” she explains. “Then you would have a very high-resolution spectral diagnostic, because the comb lines have a very high resolution; with very high precision, because the frequency of the comb lines are very precise; and in addition, it would cover a very broad spectral bandwidth, because the frequency comb is a broadband light source.”

Such a high-performance light source would find applications in sensing and imaging of ultra-fast processes, for example. However, if using frequency combs for these purposes, an equally high-resolution spectrometer would be needed to analyze the light from the sample under study. In the mid-00s, Picqué and colleagues came up with an ingenious solution: using a second frequency comb with slightly different line spacing to interfere with the light transmitted by the sample, creating a dual-comb interferometer.

“All previous spectrometers were limited by length, by geometry,” Picqué says. “If you wanted high resolution and you were using a grating spectrometer, you needed a very big grating; if you were using a Fourier transform spectrometer (typically, a Michelson interferometer with a moving mirror), you needed the mirror to move over a large distance.” In contrast, a dual-comb interferometer performs a pure time-domain measurement, meaning resolution is not limited by geometry, and the device can be extremely compact.



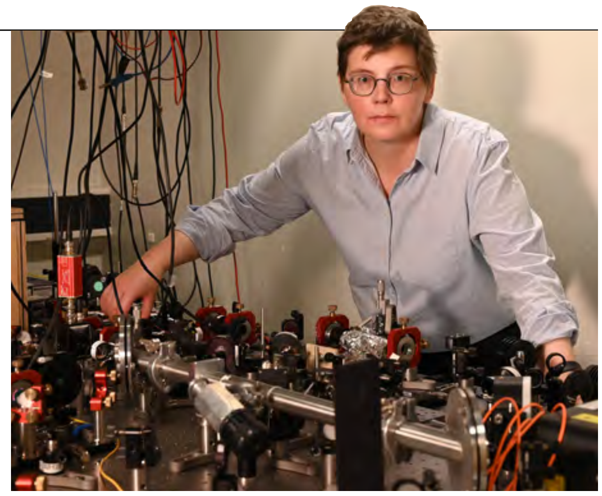
(Left) A dual-comb spectrometer. In dual-comb spectroscopy, a frequency comb interrogates the sample and interferes on a fast photodetector with a second comb, of slightly different repetition frequency, acting as a local oscillator. The interference pattern is recorded as a function of time; its Fourier transform reveals the spectrum. As all the spectral elements simultaneously on a single photodetector, it can work in virtually any spectral region, and the resulting spectra show an exceptional consistency and high quality spanning as broad a range as the emission range of the lasers. Credit: Max Planck Institute of Quantum Optics.



(Right) Principle of ultraviolet dual-comb spectroscopy at very low light intensities. The beam of a weak ultraviolet comb generator passes through a sample. It is superimposed with the beam of a second weak ultraviolet comb generator in a beam splitter. One output of the beam splitter is observed with a photon counter. Less than one click appears every twenty comb pulses. At power levels that are more than 10^6 times weaker than usual in dual-comb spectroscopy, the statistics of the detected counts contain the spectral information about the sample. Credit: Max Planck Institute of Quantum Optics.

Evolution of dual comb interferometry

As Picqué illuminated in her LASE Plenary presentation — “Optical frequency combs for interferometry from the mid-infrared to the ultraviolet range” on Monday afternoon — these advantages have seen dual-comb interferometry evolve into a major spectroscopic tool today, with significant potential for even more impact in the future.



Nathalie Picqué in her lab. Credit: Charlotte Huber, Max Planck Institute of Quantum Optics.

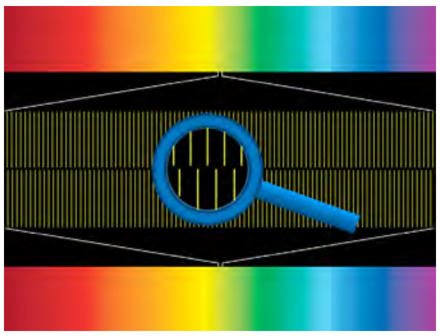
“When we started to work on it, we thought that it would keep us busy for one or two years,” recalls Picqué. “We did not anticipate all the potential.” To capitalize on this potential, Picqué leverages the additional resources afforded to her through her position as Director of the MBI to split her group’s time between bread-and-butter laboratory-based precision spectroscopy and more unusual applications outside her ordinary remit.

“We have our core activity, which is to find out whether we can push the accuracy to a point where we can contribute to some test of fundamental physics and determine fundamental constants using molecules,” says Picqué. “But more and more, we try to establish collaborations with scientists who will bring us their scientific problems and we see if our techniques can be adapted to fix them.”

These scientist might hail from biology, chemistry, physics, or more obscure fields, but they are all linked by their interest in using spectroscopy as a tool within their specialism. Be it environmental monitoring, observing the kinetics of a reaction, or some other use-case, Picqué feels that dual-comb spectroscopy’s advantages, including very high resolution, very fast measurement time, or very small form factor, might prove beneficial across many different areas.

Recently, Picqué and her team extended the capabilities of dual-comb spectroscopy to open up even more diverse applications. Featured in Nature, “Near-ultraviolet photon-counting dual-comb spectroscopy” detailed a method to engineer ultraviolet dual-comb interferometers retaining the same advantages as their conventional infrared counterparts for the first time.

There are no frequency combs that directly emit in the ultraviolet region, so instead generally researchers take infrared frequency combs and convert their frequency via harmonic generation to ultraviolet. However, this is a very inefficient process and the shorter the wavelength, the less the output power generated. “A lot of people take the path of trying to develop extremely powerful infrared lasers to solve this, so you still get a reasonable amount of light in the end,” explains Picqué. “But there are many applications where you don’t have as much light as you would like, or where you cannot use as intense a beam as you would like because, for instance, you may damage the sample.”



Dual-comb spectroscopy. Credit: Max Planck Institute of Quantum Optics.

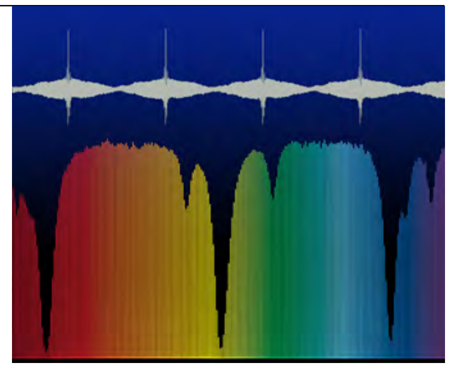
Taking a different approach, Picqué and her team asked how dim the light can be to still record spectra and benefit from all the advantages of dual-comb interferometry. It turns out that by introducing a photon counting technique, the beam can be attenuated more than a million-fold compared to the powers normally used. This allowed the team to demonstrate high-resolution dual-comb spectroscopy in the near-ultraviolet region for the first time, and therefore brought ultraviolet and even extreme-ultraviolet dual-comb interferometry a big step closer to realization.

With this step forward, dual-comb spectroscopy can go from having a typical average power at the detector higher than several tens of microwatts to measuring spectroscopic signatures at extremely low light levels, and from interrogating samples of millions of atoms or molecules to observing only a few atoms or molecules in controlled conditions.

Yet extending dual-comb interferometry into the ultraviolet regime is just the tip of the iceberg for Picqué. She wants to push the technique to the limit not only to advance her field — precision spectroscopy — but also to contribute to some of the world’s biggest challenges. For instance, she believes applying the technique to environmental gas sensing could allow simultaneous measurements of a wide range of molecules within a gas, with much higher resolution, more precision, and speed than current sensors, and in a compact relatively cheap device that could fit, for instance, inside a smart phone. Among other uses, this could prove critical for monitoring climate change, complementing satellite imagery with on-the-ground granular-level detail.

“Already there have been a lot of surprises which I have not anticipated,” says Picqué. “We will find new applications by making the effort to do more interdisciplinary work, where it will perhaps have even more impact than in precision spectroscopy.”

REBECCA POOL



Near-infrared dual-comb spectroscopy. Credit: Max Planck Institute of Quantum Optics.

Eric A. Cornell and the pursuit of precision measurement in experimental physics

The NIST physicist refuses to rest on his (Nobel) laurels.

One of the marquee events at Quantum West was the Monday plenary presentation by 2001 Physics Nobel Laureate Eric A. Cornell. His talk was intriguingly titled, "Looking for fossils of the Big Bang in the laboratory."

Cornell says, "I spoke about how you can use the tools and the technology of the experimental world—the things we associate with the world of SPIE—to the world of particle physics," which is rooted in theory and heavily reliant on huge and expensive scientific facilities like CERN and other particle accelerators.

"It turns out that there's a very direct connection," he says, "and moreover, it's a connection that is, with every passing year, becoming more compelling as some of the traditional particle physics approaches run up against their limitations." He is referring to the lasers and other devices familiar to optics engineers that allow Cornell and other investigators to manipulate and control atoms and molecules for periods that satisfy their experimental purpose.

Per the title of this talk, Cornell explains that when the largest telescopes can't see all the way back to the Big Bang, and when the highest-energy accelerators cannot produce more massive particles, what next? He says laboratory-based precision measurements offer glimpses into the distant past and into the ultra-high-energy present.

"I showed how some of the most precise laboratory measurements are performed," he says, "with particular focus on measurements of the dipole moments of two relatively light particles, electrons and muons. I tried to put the results in the context of the broader search for physics beyond the Standard Model."

Cornell is a senior scientist at the US National Institute of Standards and Technology, a Fellow of JILA, and professor of physics at the University of Colorado, Boulder. His research interests have included various aspects of ultracold atoms—in particular, Bose-Einstein condensation in strongly interacting Bose gases (for which he shared the Nobel Prize), and related few-body physics. He is also working on using precision molecular spectroscopy to explore possible extensions to the Standard Model of particle physics. His most recent research includes a project to measure the electric dipole moment of the electron.

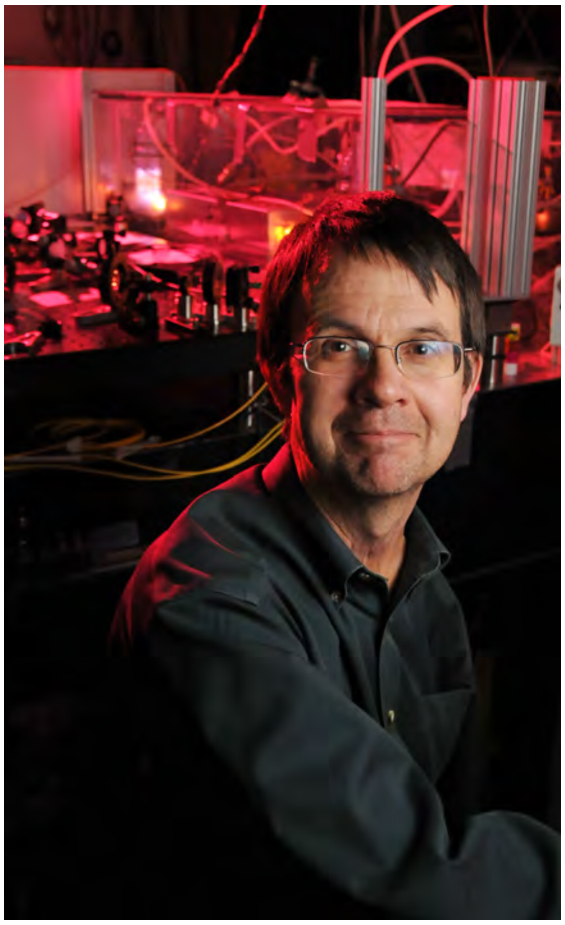
For his plenary talk at Quantum West, Cornell says, "I gave a talk which sort of assumed my audience has exactly zero particle physics background. Hopefully I,, without drowning people in all the jargon and the vocabulary, gave a very rough notion of where precision measurements can fit into what physicists would call the 'unexplored perimeter space' in particle physicists.

That space, Cornell says, is the search for hypothetical new particle physics that we are not actually able to see in existing accelerators or even would be in accelerators anticipated to come online in the next 10 or 20 years.

The story begins where Cornell's Nobel Prize winning research on Bose-Einstein candidates trails off. He says he wanted to pursue new problems, but he also knew that it would be a trap to think that new lines of research would have to be Nobel-worthy.

"I wanted to start something dramatically new, which is the precision metrology branch of my research. That ramped up to the point where it kind of squeezed out the cold atoms stuff.

So, working with CU-Boulder physicist Jun Ye and others, Cornell set out to determine the shape of the electron's charge distribution to unprecedented precision. They determined that the distribution of electron charge in the electron is essentially spherical, a measure so precise that it could facilitate discovery of new subatomic particles.



2001 Physics Nobel Laureate Eric A. Cornell in his lab.
Credit: Hans Mehlin.

"The experiments we're doing here and other eEDM-type experiments around the world — they're sensitive to stuff that accelerators can't get to. And we're looking at another factor of 10 in sensitivity over the next few years. And so, yes, I'm very excited about that."

The Standard Model in physics, it seems, cannot explain the dominance of matter over anti-matter in our universe. The imbalance suggests undiscovered physics and so many extensions to the Standard Model seek to explain the imbalance by predicting the existence of exotic new particles.

But finding new subatomic particles is no mean feat, requiring multibillion dollar facilities like the Large Hadron Collider (LHC) at CERN that was used to detect the Higgs boson.

Cornell and his colleagues, however, say that the fluctuations of the fields associated with undiscovered particles can interact with known particles making small modifications to their properties, for example, inducing an electric dipole moment of the electron (eEDM). The size of the induced eEDM is dependent on the masses of the new particles.

To date, no eEDM has been detected, but having presented the most precise measurement yet of the eEDM using electrons confined inside molecular ions, subjected to a huge intra-molecular electric field, Cornell's team contends it has reached, with tabletop capability, sensitivity to new particle detection beyond the direct reach of the LHC or any other near- or medium-term particle collider.

"That's very much on the horizon," Cornell says. "The experiments we're doing here and other eEDM- type experiments around the world—they're sensitive to stuff that accelerators can't get to. And we're looking at another factor of 10 in sensitivity over the next few years. And so, yes, I'm very excited about that.

Cornell shared the 2001 Nobel Prize in Physics with University of Colorado/JILA/National Institute of Standards and Technology (NIST) colleague Carl Wieman; and Wolfgang Ketterle of Massachusetts Institute of Technology. The three researchers were lauded for having achieved Bose-Einstein condensation in a gas of rubidium atoms at very low temperature, and for fundamental studies of the properties of such condensates.

Asked what it was like to win the Nobel Prize so early in his scientific career, Cornell replies, "Very often, [winning a Nobel] is kind of like a punctuation mark at the end of a career, and then one goes and gives talks and sits on blue ribbon commissions and so on. And those are all important things to do. I did give a lot of talks and sat on some commissions, but at the time I won I was 39 years old, and that is really too young to become a professional Nobel laureate."

Indeed, work on Bose-Einstein condensates (BECs) would consume another 15- to 20-years' worth of work in Cornell's lab. In BECS, he, Wieman, and Ketterle produced an exotic new form of matter for further investigation, work that has since unlocked complex quantum phenomena like superfluidity and

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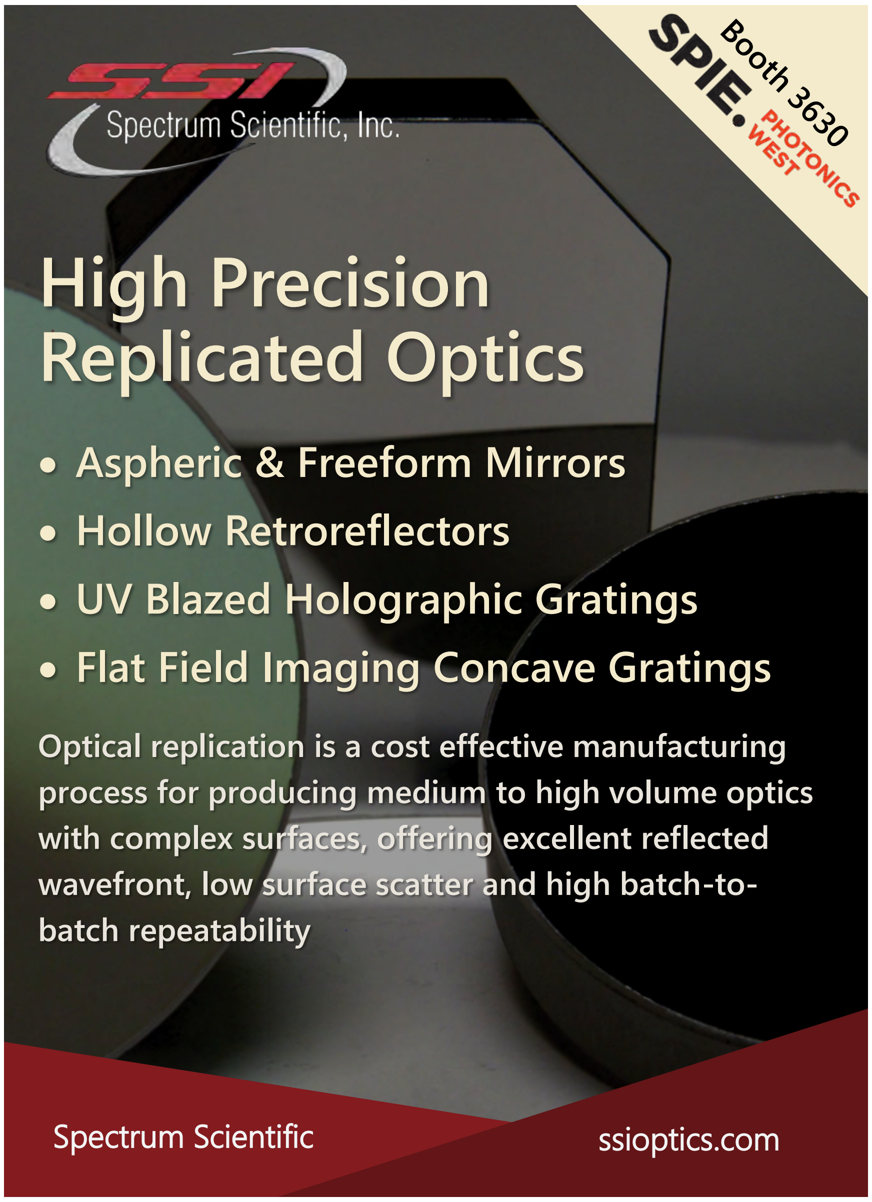
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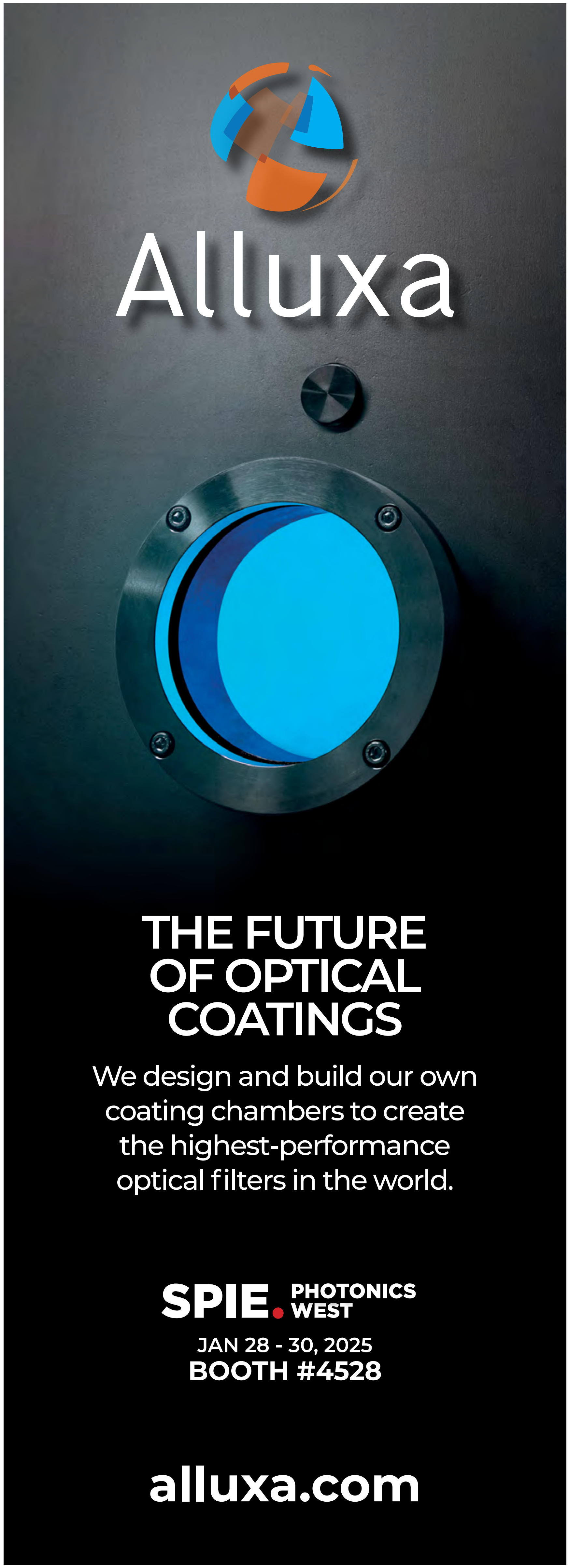
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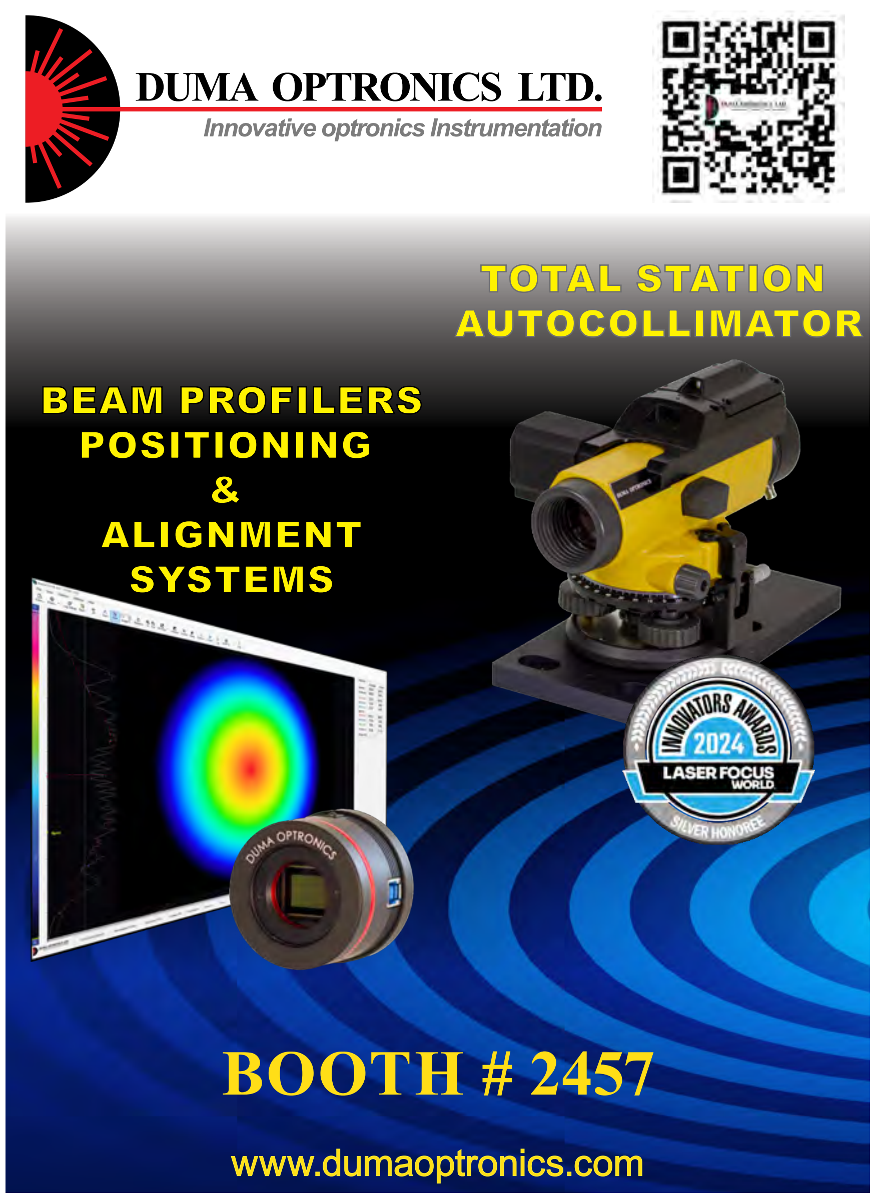
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Cornell continued from page 20

superconductivity, and with potential applications in areas like advanced atomic clocks, ultra-sensitive sensors, and quantum computing.

The condensates were long predicted to be achievable. In 1924, Indian physicist Satyendra Nath Bose made theoretical calculations regarding light particles. He sent his results to Albert Einstein who, in turn, extended the theory to a certain type of atom, predicting that if a gas of such atoms were cooled to a very low temperature, they would suddenly gather in the lowest possible energy state. The term "condensates" derives from the phenomenon's similarity to the formation of drops of liquid from a gas.

In 1995, Cornell and his fellow laureates succeeded in achieving this extreme state of matter. Cornell and Wieman produced a pure condensate of about 2,000 rubidium atoms at 20 nK (nanokelvin), which is 0.00000002 degrees above absolute zero. Ketterle performed corresponding experiments with sodium atoms.

After receiving the Nobel, Cornell says he happily spent a few years being "a sort of ambassador for physics," but after a couple more rounds of Nobel Prize winners being announced, he saw it was time to turn his attention back on his work.

"I was grateful to the field for the recognition," he says. "But I also realized that that was not a sustainable lifestyle or a sustainable career. One of the things that I really wanted to think about in a very self-conscious way is [that] you can win a Nobel Prize, and then you think 'It's only worth doing experiments that will win me a second one.' And that's not a very productive way to do physics, you know."

But Cornell first had to survive a medical horror story. Somehow, through a cut or a scratch perhaps, he had contracted an invasive and deadly flesh-eating streptococcal infection. He went to the hospital on 24 October 2004 because of a gnawing and worsening pain in his left shoulder, never suspecting that the next day doctors would be forced to remove entirely the shoulder and his left arm. His torso required skin grafts.

Barely clinging to life, Cornell was placed in a medically induced coma. He would not return home until December of that year.

"When I got out of the hospital, my travel sort of had a step-function downward," he recalls on a note of very dark humor, "I spent a lot of time not doing physics or traveling, but physical therapy and other boring things. But I got through that eventually."

2001 Physics Nobel Laureate Eric A. Cornell (L) receives the Nobel Prize in physics from King Carl XVI Gustaf of Sweden (R). Credit: Henrik Montgomery / Scanpix Sweden.

He went back to the lab. Of the years spent working on BECs, Cornell says he is proud of the work he and his graduate students have achieved.

"But it's also the case that I wanted to start something dramatically new, which is the precision metrology branch of my research [that is, eEDM]. That has ramped up to the point where it kind of squeezed out the cold atoms stuff.

"I'm happy that over the years since the Nobel I've pursued a mix of short- and long-term projects," Cornell continues. "If I had strictly gone with the 'go big or go home' philosophy back in 2001, that probably would have been the last you ever heard from me."

WILLIAM G. SCHULZ

Tying photonic knots in space and time

In his OPTO Plenary, Alexander Szameit argued that photonics harnessing global topological properties in both space and time opens the door to exciting new physics, new phenomena, and potentially entirely new applications.

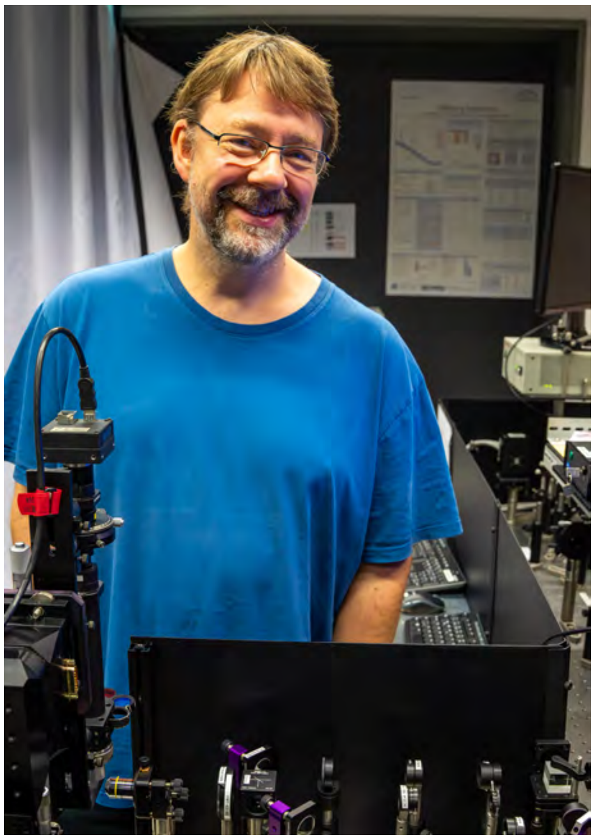
Leafing through the Photonics West program, you might have raised an eyebrow when you see the title of the OPTO Plenary talk by the University of Rostock's Professor Dr Alexander Szameit: "Topology in space, time, and space-time." This is because topology is traditionally regarded as a somewhat abstract branch of mathematics. You might even ask, what on Earth has it got to do with photonics?

In topology, the big-picture aspects of objects matter most. From the perspective of a topologist, a bath is no different from a bowl, a mug is the same as a donut. But the bath/bowl is a completely different object to the mug/donut, because they have a different number of holes, i.e. 0 and 1, respectively. Topology connects these big-picture global properties with local ones, providing the rules under which you can contort the object without transforming it into something else. For example, in 2000, Thomas Fink and Young Mao treated necktie knots as inherently topological structures and in doing so found 85 different ways to tie a necktie — some of which were new to fashion.

Arguably more interesting and useful has been applying a topologist's mindset to physics problems. Topological arguments have been used to derive properties of black holes, describe various physical phenomena like superfluidity, and even discover new (topological) phases of matter in electronic materials. Due to topological phenomena having an intrinsic robustness, qubits consisting of theoretical quasiparticles known as anyons have even been proposed as a route to fault-tolerant topological quantum computing.

Where topology has had less impact and, indeed, seems to have little bearing is in photonics. "In the end, photonics is an electromagnetic wave and interference," says Szameit. "So, one simply does not expect topological behavior — this just seems too crazy."

However, since their first demonstration in 2009, topological states of electromagnetic waves can and have been achieved, in the process giving birth to the field of topological photonics and revolutionizing fundamental understanding of how light can be manipulated.



Alexander Szameit. Credit: Robert Leppin.

"99% of physics takes place in space. Wouldn't it be cool to really think about time?" asks Szameit

Now for something completely different

Topological photonics is entirely different from other types of physics utilizing topology. Much of this boils down to the basic nature of the fundamental particles under study. Photons are bosons, whereas electrons are fermions. They therefore exhibit profoundly different behaviors. For example, where electrons naturally anti-bunch, photons are the opposite, as Szameit explains in more detail: "If you shoot two electrons at a beamsplitter, they never leave it as a pair, but if you have two photons going towards a beamsplitter, they leave the beamsplitter only as a pair," he says. "It's really, really, fundamentally different, and these concepts have to be taken into account when one thinks about topology."

In a recent joint effort with collaborators, Szameit took advantage of this fundamental difference to reproduce the Hong–Ou–Mandel effect where perfect interference between two photons entering a beamsplitter results in them having a 50:50 chance of exiting together in either output mode.

The Hong–Ou–Mandel effect was first demonstrated in 1987 and has since become a critical physical mechanism for logic gates in cutting-edge optical quantum computing. However, it is delicate, with the beamsplitter requiring extreme precision assembly. Szameit's version topologically protects the photons to always yield a 50:50 beamsplitting ratio, even with a far from perfect setup.

Alongside taking advantage of the specific features of electromagnetic waves, Szameit and others are also transferring concepts from the topological states in condensed-matter physics to light, which is no mean feat. "Many, many of the algorithms and concepts were implemented or invented for fermions, so one really has to think about the fundamentals and adjust everything, because we now have to apply them to electromagnetic waves," he says.

Some of Szameit's earliest world-firsts came from exploring this research direction, i.e. transferring ideas from topological states in condensed-matter physics to light. Based on laser-written photonic waveguide lattices they made themselves, his group was the first to demonstrate the photonic version of topological insulation, topological creation and destruction of edge modes, and a number of other phenomena.

It's about time

However, in his OPTO Plenary, Szameit took a step beyond these research areas, focusing instead on a much more fundamental subject that "challenges the mind": the new physics, new phenomena, and new applications made possible when considering topological effects in photonic systems not just in space, but also in time, and even spacetime. Szameit says that, generally, topology is considered in real space, with time just a parameter: "99% of physics takes place in space. Wouldn't it be cool to really think about time?"

Yet doing so is fraught with difficulty. Up to now, topological features have been observed as robust, long-lived states residing within an energy gap localized at a spatial topological interface. Time- or spacetime-topologically protected states require an equivalent temporal interface. "And now comes the problem," says Szameit. "In space, reflection is intuitive: you have a forward-propagating wave, an interface, and a backward-propagating one. In time, that's tough — one cannot really have waves that move backwards in time."

Although often considered as two sides of the same coin, unlike space, time has a unique unidirectionality, often called the arrow of time, which is intrinsically bound to the notion of cause and effect, i.e. causality. And this places a number of new constraints on time and spacetime topology. In fact, never being able to move backwards in time means the entire concept of an interface changes, creating a new notion of a spacetime-topological event, where a topological state localizes at a single point in spacetime.

Szameit attempts to elucidate this further by picturing such a state: "Suddenly you see in front of you a bright spark. It's localized and it's topologically protected in space and time, so it's robust. But it disappears again and when it's gone, it's gone."

Though this idea and the concepts surrounding it seem abstract, Szameit's OPTO Plenary delved into the progress his team has made in not only developing theory around time and spacetime topology, but also conducting experiments demonstrating time-topological states and even spacetime-topological events. What is more, he described the implications and new possibilities such studies open, including applications such as spatiotemporal wave control for imaging and communication, and topological lasers.

Though he acknowledges some of the content of the talk might be unfamiliar to the audience, Szameit hopes the "cool physics" involved was fascinating to Photonics West attendees. "This is my message: when you think about conventional phenomena in space, what would happen if you transferred them to time? In many cases, it would be really different, utterly interesting, and would open the door to really new physics, new phenomena, and probably new applications."

BEN SKUSE

Quantum West Business Summit: Join the leaders of the Quantum 2.0 revolution

From building a workforce and growing funds to scaling the supply chain and tapping into artificial intelligence, this year's Business Summit explores the progress, the pain-points, and the promise of quantum technologies.

It's easy to see why this year's Quantum West Business Summit, taking place from 27 to 29 January, focuses on overcoming challenges in quantum technologies for the market place. Myriad countries have declared quantum of national interest while global consultants McKinsey report "Quantum technology could create value worth trillions of dollars within the next decade." And although VC funds dipped last year, this was less than all start-up investment, and public funds are up more than 50% over 2022.

With steady investments signalling the ongoing rise of quantum, Bob Hainsey, SPIE Director, Science and Technology, and Quantum West Business Summit coordinator, has been keen to draw in industry experts, focused on moving new technologies to market, to this year's program. "When you have an emerging technology, like quantum, you have to get it from the lab into the real world, and that's a long, arduous path that we're going to address," he says. "We're looking at the challenges, the opportunities, the supply chain gaps — what does it take to manufacture a robust product in a seven by 24 process, alongside legal, policy, and IP elements — all of which intertwine."

The Summit kicked off on 27 January, with "Building a Quantum Workforce" where Royal Society University Research Fellow and Imperial College London Lecturer, Jessica Wade, lead a panel session on creating a pipeline of talented, well-trained scientists and engineers for the quantum sector. "The State of Quantum" panel session followed, providing both government and industry perspective on recent activities.

Today, on day two, 28 January, the hot topic of quantum and artificial intelligence will be addressed. "It's this big, exciting topic that was too tempting to pass up," highlights Hainsey. Throughout the day, key players from industry giants, including IBM Quantum, Microsoft, Google Quantum AI, and Nvidia, alongside up and coming start-ups such as Q.ANT, Great Sky, and QuEra, will explore where the intersection of the technologies will lead industry. Alex Challans, CEO of market intelligence providers, Resonance and Quantum Insider, will talk about "The Market Potential of AI and Quantum for Transformative Compute" in his keynote session, and will appraise the potential for long-term value creation of quantum with AI.

"Large corporates are already implementing AI in their enterprise processes to save time and money... and putting R&D budget behind the technology as it can drive immediate impact," he says. "We do not see any real deployed use of quantum computers yet but what we do see is [heads of research divisions] conceptually gluing together quantum and AI — they use the immediate promise of AI to get their research budget, knowing that what's actually more exciting in the longer term may be quantum."

"It's tactical — quantum isn't necessarily driving value today but those motivated to drive long-term innovation in an organization use AI as a means to continuing their funding," he adds.

Right now, AI and quantum computing remain distinct fields but their intersection is set to redefine what is possible for data processing and problem-solving, and will have a profound effect on each. For example, training a deep learning model demands extensive iterations across huge datasets, consuming vast amounts of computational power and energy — but quantum algorithms reduce the numbers of iterations required, reducing energy consumption. Meanwhile, machine learning can be integrated to quantum error-correcting codes to help prevent decoherence, raising compute reliability.

The combined technologies offer huge potential but as Challans also highlights, AI is a hugely hyped market right now. "There's this expectation that you can just slam a quantum computing device with, say, ChatGPT, and you've solved all the issues in drug discovery — but we're not there yet," he says. "AI will accelerate certain parts of the molecular simulation stack, and we will eventually see intractable problems become tractable, but this is a complex space."

Back to reality

While day two takes a peek at the promise of quantum and AI, the Summit's third and final day, 29 January is, as Hainsey says: "focused on the nuts and bolts stuff." The day starts with the panel session, "Burning the Ghost Light — Economic Opportunities to Scale the Photonics Supply Chain," moderated by Austin S. Lin, who supports quantum standards development at Google.

Set up to explore today's supply chain pain points, the session includes panellists from UK-based Nu Quantum, Qblox of The Netherlands, as well as PsiQuantum and DRS Daylight Solutions, both from the US. They will look at challenges facing the photonics industry and explore how standards can mitigate risks around sourcing critical quantum components that may well be custom or come from a single supplier — a topic close to Lin's heart.

Alex Challans, is CEO of market intelligence provider, Resonance, which includes Quantum Insider, Space Impulse, Digital Twin Insider, Climate Insider, AI Inside and Quantum Insider. His Keynote session looks at the market potential of AI and quantum for transformative compute.
Source: LinkedIn.

"For anyone in a supply chain, these are not new risks but they are challenging for those in quantum as its technologies are so nascent — we have no decades of iteration out in the market place, everything is starting from a bespoke state," says Lin. "So now, as an industry, we need to work out how to take the technologies from something bespoke to something that is more available — and aligning on standards specific to quantum can enable that."

"I think for most people when they hear the word standards there's a bit of an allergic reaction and they expect tons of paperwork," he adds. "But I have this mantra, "Scale Quantum, Not Bureaucracy." We need to show that standards are this enabling factor, and not just things that sit on a shelf."

Earlier this year, Lin also took the position of Head of the newly-formed United States National Committee for IEC/ ISO Quantum Technology Standards (JTC 3). Joint IEC/ISO technical committees are rare — the last one formed back in 1987 to set standards for the then fledgling information technology sector — and Lin is hopeful that insight from his Panel Session will feed back to the new committee.

"Panelists come from quantum startups as well as quantum-adjacent businesses that already have established product lines but are looking to invest in the quantum sector," he says. "These different perspectives will inform where the standards world should be going and also help industry consortia such as QED-C, UK Quantum, and Quantum Industry Canada, to develop supply chains and address our pain points."

However Lin also emphasizes how quantum standards are now truly necessary, given the rising investment in quantum technologies — around the world. As he points out, nations, including the US, UK, Canada, Japan, South Korea, and China, have together committed some $40 billion to the sector over the next decade.

"With JT3, we now have this show of support from 27 member countries and this will help enable some of that $40 billion [committed by world governments]," he says. "The clear way to do this is to align on quantum standards, which prior to this have not existed at this scale."

Challans also points out how worldwide government funds, rather than VC investment, are supporting the quantum market right now. But as he highlights: "We should be reminded of the government support that was provided to the likes of Tesla, SpaceX, and many other players operating in disruptive technologies. These companies wouldn't be here without [their] entrepreneurs but they have also benefited materially from government support."

The final day of the summit also includes a panel discussion on how optical frequency combs can be used in numerous quantum applications. According to Hainsey, executives from three leading suppliers of frequency combs — Toptica, Menlo Systems, and Vescent — will be joined on stage by representatives of the US government's National Institute of Standards and Technology (NIST) and end user, Vector Atomic, to discuss the opportunities and challenges in the continued evolution of these subsystems. "This session provides a deep dive into this key element of the supply chain," he says.

Austin S Lin supports quantum computing standards at Google, and is Chair and Head of the United States Delegation to the IEC/ISO Joint Technical Committee on Quantum Technologies Standards. He is moderating the panel session: "Burning the Ghost Light — Economic Opportunities to Scale the Photonics Supply Chain." Source: LinkedIn

The Summit closes with "The Path from Startups to End Users in Commercializing Quantum Sensing Technology." Here executives from UK and US government, start-ups, and established corporations — Hamamatsu and Boeing — all working in the quantum sensor sector, will take a look at how to migrate a novel technology to commercial application.

Hainsey is looking forward to this session, saying: "It is a little different as it's a series of presentations rather than a panel session." As he points out, the industry players will look at quantum sensor technology challenges, and explore how you build a successful enterprise and robust ecosystem.

"Right now, quantum sensors are the most near-term application of all quantum technologies in that you can see them deployed in the field," he says. "We all like to finish on a success story, right?"

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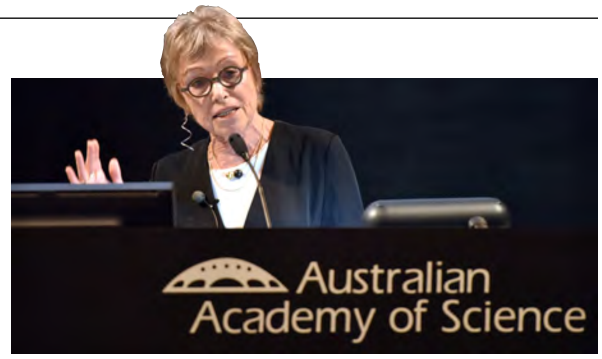
Light matters

Halina Rubinsztein-Dunlop, the 2025 SPIE Gold Medal recipient and Australia's first female professor of physics, is passing her motivation on to new generations.

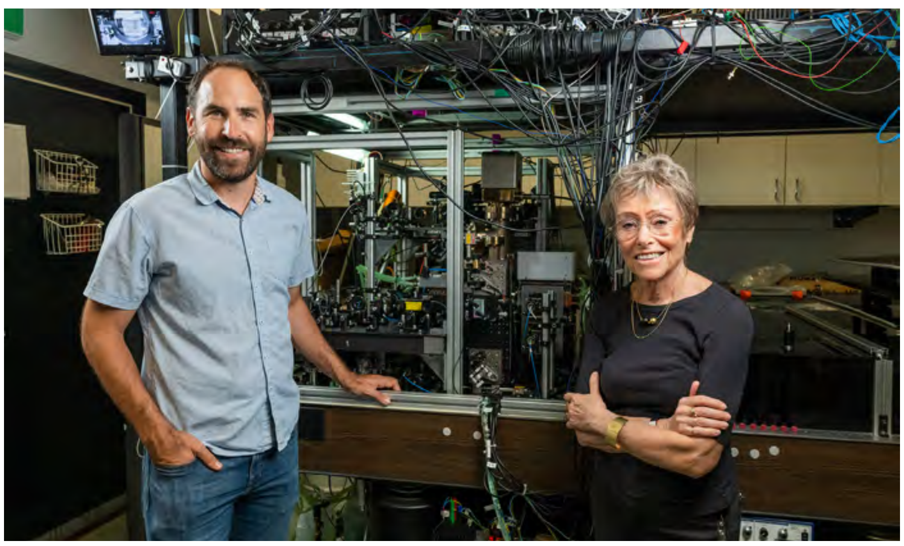


Halina Rubinsztein-Dunlop. Credit: Mark Graham.

To say that Halina Rubinsztein-Dunlop is busy is like saying the speed of light is kind of fast. On 25 January, at Photonics West, the University of Queensland (UQ) professor of physics gave a keynote presentation on optical micromanipulation in mechanobiology. On 26 January, she moderated a panel on the future of quantum biotechnology.

On 27 January, she was a panelist along with other quantum experts discussing how to build a quantum workforce — and served as session chair for the Quantum West plenary session on the same day. On 29 January, her invited paper "Shaping linear and angular momentum transfer to matter" will be presented by Alexander B. Stilgoe, a former PhD student and now Senior Research Fellow on Rubinsztein-Dunlop's team at UQ. Also at Photonics West, she's serving as conference chair of the Complex Light and Optical Forces XIX conference.

This hectic pace is standard operating procedure for Australia's first female physics professor, but at the university, no matter how busy, her priority is working with her students. "A typical day is a very busy day, and the best typical day is one filled with new ideas, new experiments, and plenty of discussions," says Rubinsztein-Dunlop. "But the best days are when I can think about my science and discuss projects and disturb my students and postdocs in the lab. Our discussions are highly inspirational and productive. The motivation I get from the new generation of scientists is absolutely fantastic."


Rubinsztein-Dunlop with the co-lead of their experimental lab in quantum atom optics, Dr. Tyler Neely, an associate professor in the University of Queensland's School of Mathematics and Physics. Credit: University of Queensland

Rubinsztein-Dunlop's long career in physics has also been highly inspirational and productive. A pioneer in the exploitation of the mechanical action of light, her work has garnered national and international awards, including Officer in the General Division of the Order of Australia, the Australian and New Zealand Optical Society's W.H. (Beattie) Steel Medal, the Australian Institute of Physics' Harrie Massey Medal, and the Eureka Prize for Excellence in Interdisciplinary Scientific Research.

An SPIE Fellow, Rubinsztein-Dunlop received both the 2024 SPIE Directors' Award and the 2025 SPIE Gold Medal. She has served on the SPIE Board of Directors, the Fellows, Publications, Symposia, and Strategic Planning committees, and multiple conference program committees.

Opening to a new world

Rubinsztein-Dunlop is most noted for her pioneering work in the field of optical physics and is widely recognized for her contributions to quantum optics, nano-optics, and laser physics. Using the power of optics and lasers to explore quantum and biological phenomena, her research has had significant impacts on the development of quantum technologies, including a broad range of novel quantum sensors and devices.

"I do love laser technology and laser applications," says Rubinsztein-Dunlop, who over the years has observed laser technology shrink from room-sized machines to the micro devices used today. "I belong to the generation of physicists who saw the laser enter our labs and we were trying to use them in a lot of areas for the first time ever. The studies of light matter interactions became so much more reachable, enabling new science when using lasers. It was like a new world opening its doors to science. There were so many possibilities in untapped areas of optics and photonics. And the development of laser technology was all so fast, giving us even more opportunities for doing beautiful physics. So, the excitement was there all the time!"

One of her key contributions is in the area of optical tweezers, where she has worked on techniques to manipulate microscopic particles using focused laser beams. Because they can be highly precise, optical tweezers are valuable tools for investigating microscopic and nanoscopic phenomena without making physical contact. "The key advantage of optical tweezers, scissors, and structured light illumination over mechanical prodding, poking, and sorting, is that they normally do not damage the fragile and soft structures that make up the cells of living organisms," says Rubinsztein-Dunlop.

Other accomplishments include producing one of the first Bose-Einstein condensates, the coldest states of matter in the known universe, in the Southern Hemisphere, with her team at UQ. She and her team also designed and built atomic circuits using cold atoms — the atomic analog of modern electronic devices — an important development for future quantum machines. Rubinsztein-Dunlop's group in laser micromanipulation/optical tweezers was the first to demonstrate the transfer of angular momentum of light to microscopic particles. This work led to several innovative applications in optically driven microsystems.

Great mentors and fantastic blinkers

Another of Rubinsztein-Dunlop's firsts was becoming the first female professor of physics in Australia in 2000. "When I was told by one of my Australian physics friends that I was in fact the first female professor of physics, I thought he was joking," says Rubinsztein-Dunlop. "I just could not believe that there were no female professors of physics in Australia before me."

Rubinsztein-Dunlop adds that some of the credit for this achievement goes to Professor Elsa Garmire who asked to speak to her after a review of the physics department. "She basically said she didn't understand why I wasn't a professor and how was it that I didn't apply for promotion," says Rubinsztein-Dunlop. "She was scary, but a fantastic role model at the same time. I strongly believe that she instilled in me strong values that I will never forget and on which I still build."

Possibly the greatest mentor for Rubinsztein-Dunlop was her mother, who was also a physicist, but didn't necessarily push science as a career on her children. She inspired them to go for what they liked best. Rubinsztein-Dunlop's original career choice was music studies. "The greatest thing that she gave me is the belief that I can do anything that I set out to do," says Rubinsztein-Dunlop. "So, the problem of choosing what to study had to do more with the culture that she grew up in and the life that she lived. I think that she felt that music history, although very interesting, would not secure me a job in the future. So, she just asked whether there was anything else that I could think of. I was rather good in math and physics, so I thought one of those things would do for me. But since my older brother was a super-gifted mathematician, math was out. Physics was the third choice, eventually proving itself to be my favorite. It took me some time to realize that, though."

The road to becoming an icon in the world of physics wasn't always smooth. In several interviews, Rubinsztein-Dunlop has talked about developing "fantastic blinkers" which help one ignore comments or situations where others try to belittle you, or don't believe in your abilities. She notes that comments toward her were often gender-based, such as "women cannot be good experimentalists," or "she will never finish her PhD as she doesn't have what it takes." Fantastic blinkers came in handy as protection from such and views.

Today, Rubinsztein-Dunlop shares her mentors' lessons — and her blinkers — with her students. "I strongly believe that the most important aspect of my work is to provide guidance — scientific, technical, and moral — and support to upcoming generations so that they can proceed with their careers in a way they find most relevant for themselves," she says. "To see a new PhD student taking charge of a project, to see them develop and get excited about their work, to see them coming up with new exciting ideas and developing them, is fantastically rewarding and beautiful."

KAREN THOMAS

Silicon photonics faces intense competition

Will photonic integrated circuits (PICs) shift to alternative material platforms?

Photonics integration is a growing trend, offering numerous advantages such as miniaturization, power efficiency, improved performance, cost reduction, scalability, high-speed data processing, and a platform for novel functionality. AI data centers face unprecedented demand, driving a new era of scalable infrastructure and sustainable solutions. This trend opens up new and equal opportunities to various photonic integrated circuit (PIC) technology platforms. Silicon PICs are compatible with CMOS (electronic) fabrication, allowing them to be manufactured using established foundry infrastructure.

Additionally, new electro-absorptive materials for EO modulators, such as Thin-Film Lithium Niobate (TFLN), Barium Titanate (BTO), and organics, can be integrated into PICs, significantly improving bandwidth and energy efficiency. The need for new materials in future photonic integrated circuits offers the possibility for alternative platforms like LNOI and InP. Intense competition is expected since lithium niobate seems to be more efficient as an individual platform and InP is also waiting for its killer application when silicon runs out of steam. It is anticipated that recent progress in PICs will also create a highly competitive environment with discrete devices like VCSELs and EMLs.

Toward mainstream adoption: trends to watch

The silicon PIC (dies) market was worth \$95M in 2023 and is forecast to grow to more than \$863M in 2029 at a 45% compound annual growth rate (CAGR 2023-2029). This growth will be driven mainly by high-data-rate pluggable modules for increased fiber-optic network capacity. Additionally, projections of rapidly growing training dataset sizes show that data will need to use light to scale ML models using optical I/O in ML servers. The Lithium Niobate on Insulator (LNOI) market for Datacom is expected to reach nearly \$1B in 2029, reflecting a compound annual growth rate for the period (CAGR 2023-2029) of almost 100%. Integrating TFLN modulators on an SOI platform is currently being explored alongside the LNOI platform, but a preferred platform has yet to be determined.

Regardless of the choice, the overall cost of a PIC is expected to be largely influenced by the price of the TFLN modulator. If LNOI becomes the preferred platform, SOI will likely lose market share. TFLN or LNOI technology stands out due to its impressive attributes of low optical loss and high bandwidth capacity. Its strengths in key performance metrics and ease of integration make it a intense contender in optical innovation. As the technology matures and finds broader applications, production economies of scale are expected to drive down the cost, making TFLN increasingly viable for mainstream adoption.

Two pathways: a push toward higher lane speeds

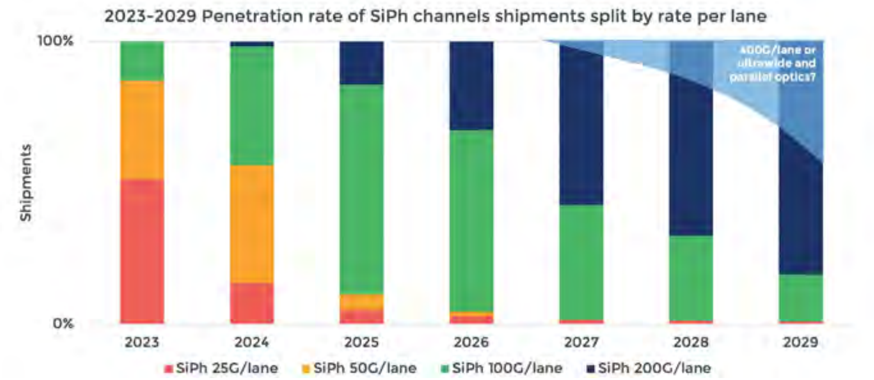
By 2026-2027, a transition to 200G per lane is anticipated, driven by next-generation AI clusters and cloud data centers. This shift will build upon ongoing developments of 400G/lane lasers and other components, opening a pathway to extremely high per-port Ethernet speeds — 3.2T and potentially beyond. Migrating to higher lambda speeds brings several benefits: a reduction in power usage by 20-30%, enabling lower cost per bit, half the number of lasers enabling lower cost per bit, and overall lower operational expenses. However, serious challenges are also expected.

Silicon-on-Insulator (SOI) requires advanced new EO modulator materials for 400G/channel applications, adding complexity and cost. Deeply integrating SOI with materials like TFLN, BTO, and organics could enable high bandwidth but at a prohibitive cost, potentially reaching economic viability by 2032-2033. There are adverse diffusion effects during silicon processing, as well as a challenging heterogeneous integration process in terms of yield. There is a vast industrial ecosystem seeking viable enhancement of silicon photonics technology.

If the industry is unable to justify paying a premium for ultra-high channel speeds, ultrawide and parallel optics may emerge as viable alternatives. Well-developed hybrid integration, which is already cost-effective for 100G/lane and soon for 200G/lane, allows systems to scale efficiently by adding more channels or fibers as needed.

Additionally, optical interposers enable the integration of multiple optical and electronic components — such as lasers, modulators, and photodetectors — onto a single platform. These interposers simplify the alignment of optical components by incorporating integrated waveguides and alignment features, reducing assembly complexity and improving production yield. Leveraging CMOS manufacturing processes, optical interposers can be mass-produced at a lower cost than traditional photonics packaging, which often requires manual alignment.

SILICON PHOTONICS: DATACOM PICS (DIES) PLUGGABLE OPTICS TRANSITIONS TOWARD HIGHER SPEEDS PER LAMBDA



Source: Silicon Photonics 2024 – Focus on SOI, SiN, and LNOI platforms report, Yole Intelligence, 2024.

Lithium Niobate on Insulator benefits from improved mode confinement and lower driving voltages due to the thin film geometry, enhancing electro-optic modulation efficiency ideal for ultra-high bandwidth applications targeting Linear Pluggable Optics, Linear Retimed Optics, and coherent lite pluggable optics. All relevant TFLN modulator suppliers, such as Hyperlight, Liobate, AFR, and Ori-chip, have developed TFLN PICs that will clearly compete with SOI in the same applications. The position might be difficult initially due to the high cost and limited mass production, but TFLN is clearly a key enabling material for 3.2T pluggable modules expected in 2027/2028.

Indium phosphide (InP) stands out for its ability to integrate active photonic components directly onto the chip, such as lasers and amplifiers. This capability minimizes the need for complex assembly, though the technology currently incurs high costs and remains at a low production volume. InP could become a formidable competitor to SOI and LNOI by 2029, especially for coherent lite applications. Infinera, Lumentum, Smart Photonics, Effect Photonics, and Bright Photonics are the major proponents of InP PIC technology.

The trend toward higher lane speeds is pronounced, but the essential task for industrials is not only to design new PICs that meet future bandwidth and power efficiency requirements but also to make them commercially viable.

Co-Packaged Optics (CPO): promises and challenges

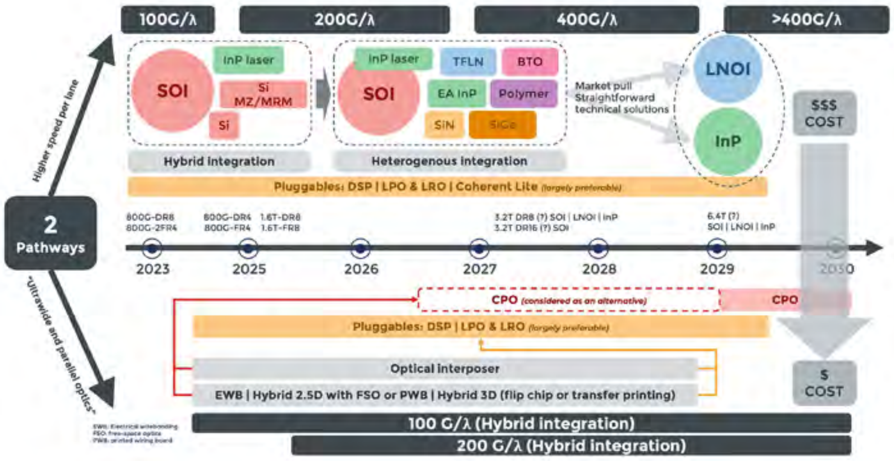
CPO has gained attention for its potential to handle the growing data rates at lower power. However, as a non-IEEE standardized solution, it presents a risk if it does not perform as expected. CPO's reliance on high-speed per channel (≥200Gbps), advanced modulation schemes like 224G PAM4, or coherent technologies complicate integration, with substantial heat generation adding to power and cooling challenges. Consequently, CPO's high-speed operation raises concerns about performance and reliability, which could make pluggable solutions a safer alternative for some applications.

Outlook

The demand for scalable, energy-efficient, and cost-effective optical solutions in data centers and networks has set the stage for fierce competition among SOI, LNOI, and InP platforms. Each offers unique strengths and challenges, shaping the future of IM-DD or coherent-lite pluggable modules and influencing the broader optical communication landscape.

MARTIN VALLO, PHD, YOLE GROUP

TWO PATHWAYS TOWARD FUTURE HIGH BANDWIDTH DATACOM OPTICS



Source: Silicon Photonics 2024 – Focus on SOI, SiN, and LNOI platforms report, Yole Intelligence, 2024.

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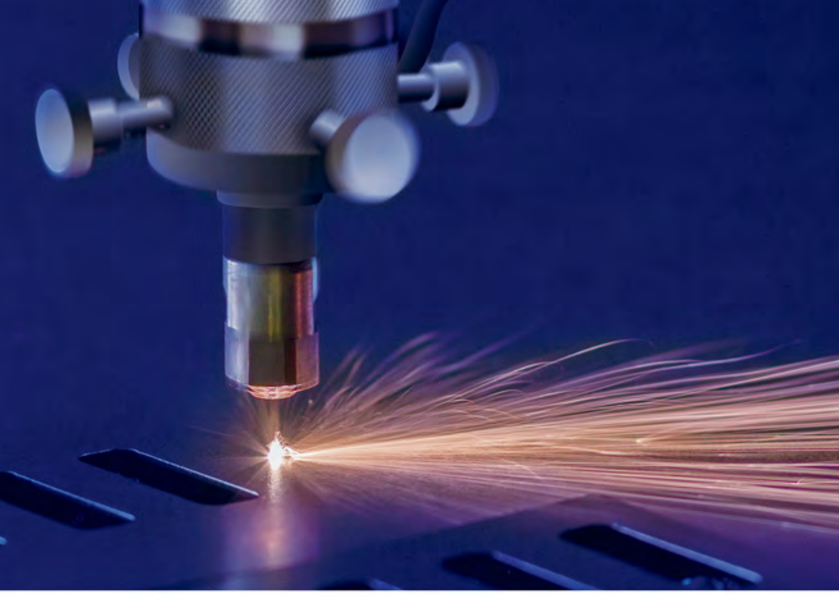

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