TUESDAY
EDITION

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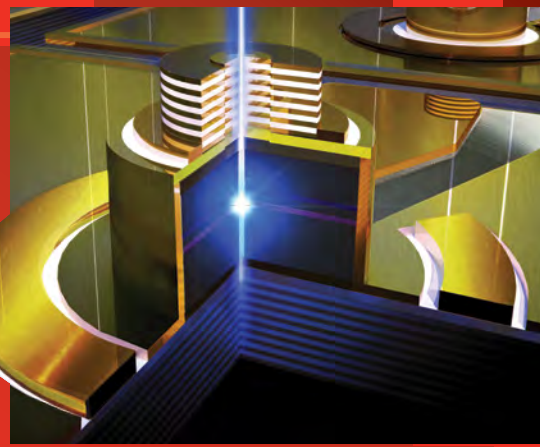
PHOTONICS WEST SHOW DAILY

Deep UV sources
p. 30



SPIE announces new $1M endowment

Funding will create the SPIE-Manchester Postgraduate Scholarship in Photonics.

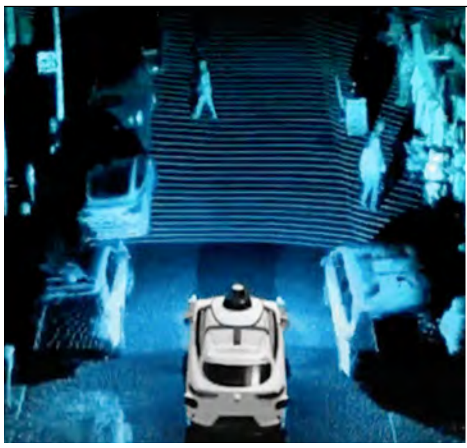
At yesterday's OPTO plenary session, SPIE and The University of Manchester announced the establishment of the SPIE-Manchester Postgraduate Scholarship in Photonics. The $500,000 gift from SPIE will be matched 100% by the University, and is part of the SPIE Endowment Matching Program. The newest SPIE matched endowment will support early-career researchers as well as returning researchers at the University's Photon Science Institute in partnership with the Royce Institute, the UK's national institute for advanced materials research and innovation.

With a goal of increasing diversity in optics and photonics, the SPIE-Manchester Postgraduate Scholarship will have a particular focus on funding individuals returning to research following a career break or time in industry, and those pursuing unconventional career pathways or part-time study (situations often necessitated by caring responsibilities, for example). Aligning current research and industrial needs for a robust training pipeline, an additional unique feature of the scholarship is an optional final-year placement of up to 12 months, during which students can develop industry-relevant skills in collaboration with local optics and photonics companies.

"This marks just the beginning of the partnership between The University of

continued on page 03

Check mates: SPIE President Jennifer Barton and Richard Curry, Vice Dean of Research at The University of Manchester. Credit: Joey Cobbs.



Safer travels: Waymo Driver's perception system takes data gathered from its suite of sensors, and deciphers what's around it — from pedestrians to cyclists, vehicles to construction — to plot its route. Credit: Waymo.

Lidar shows Waymo the way

Waymo's David Schleuning looks at the road ahead for lidar and autonomous vehicles.

For autonomous driving vehicles the world is complicated, David A. Schleuning of Waymo, told an audience Sunday at his presentation on trends in lasers and detectors for lidar. Waymo operates some of the so-called robotaxis that Photonics West attendees might see this week in San Francisco. The vehicles' sensor design needs to consider, among other aspecs, the challenges associated with cities and highways, solar background in daytime, and adverse weather conditions.

What's more, Schleuning continued, people wearing dark or light clothing results in differences in reflectivity that can be challenging for both the laser and detectors. Even things like stop signs and road signs that make driving easier for people, impacts the return of photons critical to lidar functioning. His presentation offered an overview of current technology and a roadmap for improvements.

continued on page 04

DON'T MISS THESE EVENTS.

PHOTONICS WEST EXHIBITION
10 AM – 5 PM Moscone Center, North-South (Exhibit Level)

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

NANO/BIOPHOTONICS PLENARY
10:30 AM – 11:30 AM Moscone Center, Room 207 (Level 2 South)

QUANTUM WEST BUSINESS SUMMIT: OPENING SESSION AND KEYNOTE
10:30 AM – 12 PM Moscone Center, Room 155 (Upper Mezzanine South)

LUNCH AND LEARN: OVERCOMING IMPOSTER SYNDROME IN OPTICS AND PHOTONICS
12 – 1 PM Moscone West, Community Lounge (Level 2)

STARTUP CHALLENGE FINALS
2:30 – 4 PM Moscone Center, Expo Stage, Hall DE

PAWS FOR A BREAK
5 – 7 PM Moscone West, Community Park (Level 2)

SPIE MEMBER RECEPTION
8 – 9:30 PM San Francisco Museum of Modern Art

For the full schedule, see the technical program and exhibition guide or download the SPIE Conferences app. Some events require registration.

IN THIS ISSUE.

Adaptive optics boosts OCT in eyecare, says 'Retina Chief' Richard Rosen

A hot-ticket, annual feature of the BiOS Conference is the Pascal Rol keynote presentation, which was established to promote the exchange of ideas between clinicians with a technological need and engineers interested in ophthalmology.

The invited lecture — "Spying on retina microworlds: Synergizing dynamic enface OCT and quad-fusion adaptive optics scanning laser ophthalmoscope (SLO) imaging" — was delivered by Dr. Richard B. Rosen of New York Eye and Ear Infirmary of Mount Sinai, NY.

Dr. Rosen is "Chief of Retina" of the Mount Sinai Health System and Retina Fellowship Director, as well as Vice Chairman, Director of Ophthalmology Research, and Surgeon Director at the New York Eye and Ear Infirmary.

He described his research interests, which include new treatments for macular degeneration and diabetic retinopathy, improved understanding of sickle cell anaemia, innovations in diagnostic retinal imaging, and surgical instrumentation.

OCT/OCTA are non-invasive imaging tests with well-established capabilities for ophthalmologists investigating the retina. Using OCT, one can observe individual layers of the retina, enabling diagnosis and treatment of a range of diseases.

One of Dr. Rosen's specialties is in pairing OCT/OCTA to adaptive optics SLO, which he explained, "offers a bridge between clinical and laboratory findings and provides opportunities for enhancing patient care," he said.

"In the past quarter century, enface optical coherence tomography and adaptive optics SLO imaging have exploded the ophthalmoscopic perspective, transporting clinicians through keyholes to new dimensions of retinal visualization, inviting advances in diagnosis and therapy."

Dr. Rosen said, "To bridge the clinic and laboratory divide we have developed custom instruments to further survey and probe pathologies captured with commercial instruments, expanding our clinical understanding."

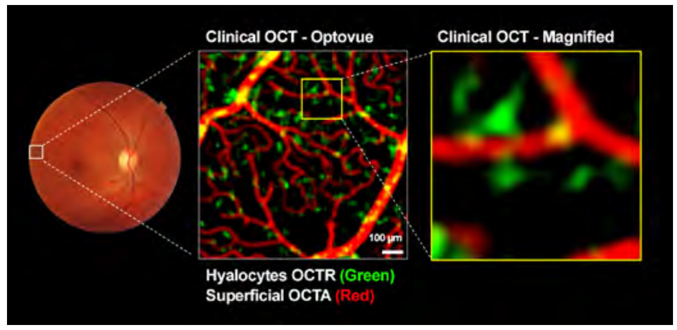
The broad sweep of Dr. Rosen's talk touched on a range of eye conditions that have become better understood and their treatments enhanced by his groups' pairing OCT/OCTA to adaptive optics SLO. Enhanced observation of blood perfusion through capillaries in the retina have improved understanding of problems including macular degeneration, sickle cell anaemia, and diabetic retinopathy.

This, in turn, has led to improved outcomes for patients, whether by drugs, surgery or, more recently, stem cell-based treatments. He commented on how photonics-based technologies have significantly enhanced the understanding and capabilities of eye specialists and surgeons to be able to treat an ever-growing range of medical problems.

"There are so many individual problems so I think we need as many tools as we can get, whether it's surgical , chemical, or the use of stem cells.

"Now photonics has brought us to the level where I can sit with a patient, and we can have intelligent conversation about the state-of-the-art of what we know about their disease."

MATTHEW PEACH



Dr. Richard Rosen, with an example of enhanced retinal images. Credit: Richard Rosen.

Optoacoustic tomography images Achilles tendons in motion

Researchers from Taiwan and Switzerland have collaborated on a new application for dynamic optoacoustic imaging, showing it is possible to observe changes in the perfusion of blood vessels in the Achilles tendon while it is exercised.

Speaking during the BiOS conference Biophotonics in Exercise Science, Sports Medicine, Health Monitoring Technologies, and Wearables V on Saturday, Amy Lin Hsiao-Chun from Taiwan's National Tsing-Hua University (NTHU) detailed the team's multispectral optoacoustic tomography (MSOT) approach, which is based around a fast-tuning optical parametric oscillator from Germany-based InnoLas Laser.

The collaboration with ETH Zurich and the University of Zurich indicates that the technique could be used in the future to help better treat tendonitis problems. So far, they have shown that the MSOT setup is able to produce three-dimensional imagery in real time, yielding an imaging depth of 2 cm and a resolution of 200 µm. Having initially demonstrated that the approach was able to image tendons within a static forearm and during dynamic flexing of toes, they then recruited eight healthy volunteers in a bid to visualize the different types of blood vessels in the Achilles tendon, a part of the body particularly prone to tendonitis injuries.

When those volunteers completed 50 heel-raise exercises, the MSOT system used four near-infrared wavelengths to image blood flow in the Achilles, and to give an indication of oxygen saturation in different types of blood vessels — all in real time.

By deploying 760, 800, 860, and 900nm wavelengths from the OPO, the team was able to measure oxygen saturation and apparently different responses in each of the three different types of blood vessels during exercise.

MIKE HATCHER

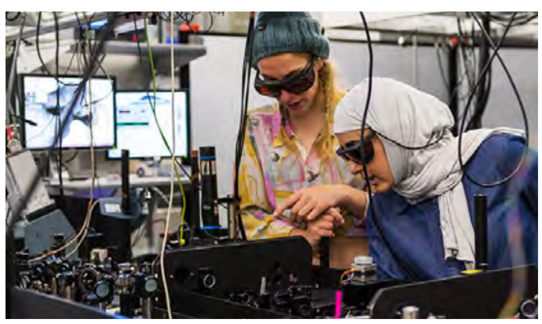
Endowment continued from page 01

Manchester and SPIE," noted the university's Department Head of Research for Physics and Astronomy Patrick Parkinson. "The establishment of the SPIE-Manchester Postgraduate Scholarship in Photonics is a testament to our shared values within skills training, fostering diversity in education and the vital role of photonics. This announcement holds special significance as it coincides with the University's bicentenary year. We take great pride in using this generous donation to not only advance research and education but also to solidify our existing partnerships and forge new industrial collaborations to deliver a doctoral training program that will ensure a sustainable workforce for the North West of England."

"Our expanding field needs researchers and engineers, though for some who might be interested in a photonics career, traditional educational paths are barriers to their success," said SPIE CEO Kent Rochford. "The SPIE-Manchester Postgraduate Scholarship in Photonics aims to remove those barriers and provide exciting opportunities for early-career researchers and those who may be pursuing unconventional career paths. Working internally at the university's Photon Science Institute with the option of an industry-focused placement, promises to benefit young researchers as well as our future diverse workforce. I very much look forward to meeting the leaders in optics and photonics technologies who will emerge from this dynamic partnership between SPIE and the University of Manchester."

This is the 11th major SPIE gift to universities and institutes as part of the Society's ongoing program to support the expansion of optical engineering teaching and research. The SPIE Endowment Matching Program was established in 2019 to increase international capacity in the teaching and research of optics and photonics. With this latest gift, SPIE has provided over $4 million in matching gifts, resulting in more than $11 million in dedicated funds. The SPIE Endowment Matching Program supports optics and photonics education and the future of the industry by contributing a match of up to $500,000 per award to college, institute, and university programs with optics and photonics degrees, or with other disciplines allied to the SPIE mission.

DANEET STEFFENS



Doctoral students working in The University of Manchester's Photon Science Institute lab. Credit: The University of Manchester.

Seeing multi-dimensionally

By designing hardware and software together, computational 3D imaging shows increasing promise

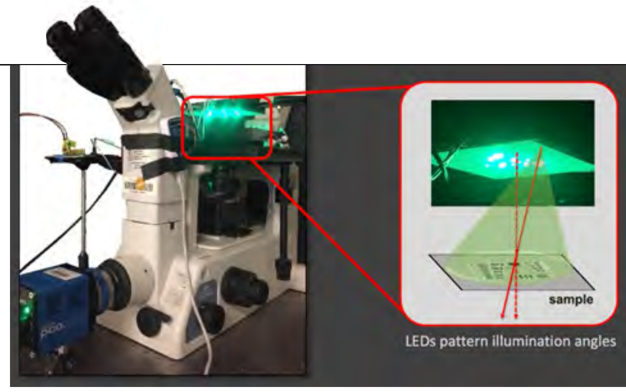
As head of the University of California, Berkeley's Computational Imaging Lab, Laura Waller develops methods for optical imaging — with the optics and computational imaging co-designed. In a presentation Sunday, she described microscopy methods for 3D imaging of thick scattering samples — embryos, for example — in both transmission and reflection mode.

"In computational imaging, you have your imaging system hardware and software that you design together, so you can efficiently encode information to measurements and then later decode them computationally," Waller said.

Such encoding is especially important for phase imaging. "I think everyone here knows that phase imaging has to be computational imaging, because we can't measure phase directly. We need to find a way to encode the phase information into our intensity measurements. And then we have to do some sort of decoding; sometimes it's very simple, but sometimes not."

Her favorite method is basic, using an LED array as the illumination unit and a brightfield microscope. "You can pattern what your illumination looks like. [The LED array] is just sitting above the sample. This thing is a really beautiful computational imaging platform: it enables all kinds of different imaging modalities, just by choosing which LEDs you turn on when you take images, and then choosing how you reconstruct the images after the fact."

For 3D imaging, Waller said, "the simple way to start thinking about this is illumination angle scanning." She showed a sample with two layers and how the layers shift with the illumination angle. "You shift what angle you're coming with illumination; things look to shift. If they're unfocused, they don't shift. If they're off focus, they shift. The more they shift, the more off focus they are, and in which direction they shift tells you what depth. You're getting 3D information. It's just another way to think about tomography."



An LED array plus a bright field microscope makes a "beautiful computational imaging platform." Credit: Laura Waller.

Biologists are very interested in her work because it would allow 3D imaging without tagging that could be harmful to organisms.

She describes the basic technique as being within the light-field framework. But the light-field reconstruction has its issues: "It was horrible by means of diffraction rings all over the place, because the light field is fundamentally a geometric construct, so it's not accounting for diffraction information. We need phase to correct for the diffraction information. We figured out algorithms to solve for phase at multiple different layers within this 3D object." Machine learning, she said, promises improvements.

Waller noted with pride that former members of her lab also continue to push the bounds of 3D computational imaging with exciting new directions in research.

WILLIAM SCHULZ

BEST PAPER AWARDS ANNOUNCED

The SPIE AI/ML Best Paper Award recognizes papers that highlight the use of artificial intelligence, machine learning, and deep learning to create and implement intelligent systems across multiple sectors, technologies, and applications.

BiOS AI/ML

Luzhe Huang
12852-42: *Self-supervised, physics-informed learning for hologram reconstruction*
January 29, 9:15 – 9:30 AM

OPTO AI/ML

Mathilde Hary
12903-55: *Autoencoders for compressive sampling in a high-dimensional ultrafast optical system*
February 1, 9:15 – 9:30 AM

The SPIE Sustainability Best Paper Award recognizes papers that highlight the use of optics and photonics for renewable energy, natural resource management, sustainable manufacturing, and greenhouse gas mitigation in support of the UN Sustainable Development Goals

OPTO Sustainability

Maxime Romanet
12893-31: *140 km Brillouin optical time domain reflectometry based on single-photon detector*
January 30, 4:40 – 5 PM

LASE Sustainability

Idriss Amadou Ali
12877-62: *A free space optical link model for C-band data and power transmission*
January 30, 6 – 8 PM (Poster Session)

UK program taps optics community for climate solutions

Two UK-based optics researchers are looking for ideas from the photonics community to help fill technology gaps in climate monitoring, with funding made available via the UK's DARPA-style "ARIA" (Advanced Research and Invention Agency) program. Speaking at Photonics West during a panel session on government funding schemes for biophotonics, Gemma Bale said that the effort was open to both UK and international collaborators.

Bale is co-director of the climate-themed ARIA program alongside Sarah Bohndiek, after the two University of Cambridge researchers were appointed to the roles in September 2023. Provided with £800 million funding overall, the ARIA team has now identified seven different "opportunity spaces" where they intend to fund disruptive, high-risk technologies with the potential to deliver major long-term benefits. Entitled "Scoping our planet: a new lens on climate science", Bale and Bohndiek's initial opportunity space document — available via the ARIA web site — outlines that although many of the Earth's key climate indicators are already monitored extensively, there are still some major gaps to fill.

ARIA program: Gemma Bale. Credit: Joey Cobbs.

"Current Earth system measurements have serious gaps that lead to uncertainties in weather forecasting and climate predictions," state Bale and Bohndiek in their document. "By harnessing the power of optics we can fill these gaps, equipping society to respond

continued on page 29

Waymo

continued from page 01

"There are a number of things to look for," he said of the cars' sensors. "Long-range lidar has really phenomenal resolution and can pick out a lot of pedestrians, people walking through the streets. Are they carrying a bag? Is that actually not a bag but a child? And if they step off the curb into the street, the car has to figure it out."

Cameras on Waymo's autonomous vehicles, Schleuning said, can be illuminated in two ways: by the solar background or by the laser itself. That means the cameras are equally effective in daytime and nighttime. "And in fact, the camera image is better signal to noise at nighttime, because it's doesn't have the noise of solar," he said. "And this is a place where now, the lidar camera does better than the regular camera, because we're not relying on the solar background to light up the scene."

There are multiple different ways to lidar, Schleuning said. The simplest is time-of-flight with a direct pulse-width ratio, and another is indirect modulation. He said he was excited to see a number of talks at Photonics West on things like coherent lidar and the lasers behind that technology, as well as time-of-flight pump or time-of-flight pulse lidar. The lasers could be semiconductor lasers, solid state, or fiber lasers.

"These are all options that make different lidars and they all have pros and cons," he said. "Our belief is that semiconductors will dominate; semiconductor lasers and silicon detectors behind them are the best path towards."

Schleuning said that recent advances in single photon avalanche detection (SPAD) technology have increased photon-detection efficiency and reduced sources of noise. And he noted improvements in edge-emitting lasers and VCSELS, particularly trends in power and beam parameter product (BPP). For edge-emitting lasers, he gave an overview of the performance of gain-guided versus index-guided lasers and resulting BPP, and for VCSELs, he summarized developments with larger diameters, more junctions, and back-side emission. Given the intensity of research effort in all of these areas, it would seem that better lidar for better autonomous driving vehicles are perhaps just around the corner.

WILLIAM SCHULZ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HIGH POWER
LOW Vπ $LiNbO_3$ PHASE MODULATOR
FOR SBC AND ANTI-SBS
• High stability across time, temperature and vibration
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Welcome to a bigger and better Photonics West

I remember closing Photonics West 2023 feeling great, still buzzing from the successful week, the technology I witnessed, and the many colleagues I encountered during the week. I still remember that wonderful feeling of accomplishment and gratitude towards the SPIE staff, our many volunteers and partners, and the photonics community for such a great week. But also the hint of anxiety about how we could ever top what had just unfolded.

The concern is gone. Without a doubt, this year is bigger and better than last year — a fantastic result from all the hard work that began last February in Bellingham, when the planning for Photonics West 2024 officially kicked off.

Part of this year's growth comes from a fourth exhibit, the Quantum West Expo, to highlight the growing commercialization of quantum technologies and the impact of photonics in this burgeoning marketplace. But that is not all — as you walk into the main Photonics West Exhibition, you will undoubtedly notice the increased footprint and how big the exhibition has grown. The photonics industry is thriving, and there is no better place to see that on display than the Moscone Center this week. We have over 1300 exhibitors participating in Photonics West, and together with AR|VR|MR, BiOS, and Quantum West, are hosting more than 1600 exhibition booths. As you walk through the exhibitions, I hope you have time to engage with the exhibitors and ask questions. The exhibition halls are more than a showcase; they're dynamic spaces where ideas come to life, and collaborations are forged.

Also on the exhibition floor, we have put together an impressive lineup of talks and panels for the Industry Program. These talks are designed to augment the exhibit and provide a business-focused look at the technologies and applications on display in the booths. The program also includes the SPIE Startup Challenge. I encourage you to stop by and hear the business pitches from the six finalists. They are all doing exciting and innovative things with photonics, and it's a great event to remind us of the energy and inventiveness of the entrepreneurial spirit that keeps our industry growing.

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

During a coffee break, strike up a chat with the person next to you. Swap stories, share insights, and embrace the diversity of experiences that make our community so vibrant.

In addition to the larger exhibitions, the conference program has also grown since last year. With nearly 100 distinct technical conferences covering everything from photonics for dermatology to agriculture and free space communication to silicon photonics, the wide breadth of photonic applications is showcased and actively discussed and developed in the conference rooms this week. With over 5000 presentations, there truly is something for everyone, but I also urge you to sit in on some talks outside your discipline. This is a great way to learn about new things and network with a new group of folks, but you may also find that you can apply the knowledge from a disparate application to find and enable innovations.

Beyond the conference rooms and exhibit halls, the week is full of networking events designed to help you make deeper connections in more relaxed settings while also having fun. Our events team plans the Welcome Reception in secret, keeping the theme and details from other SPIE staff, so I enjoyed this year's surprise along with you. It was evident by the struggles to end the party at closing time that all had fun. But also remember, these are not just networking opportunities; they're the secret sauce that makes Photonics West a must-attend event. During a coffee break, strike up a chat with the person next to you. Swap stories, share insights, and embrace the diversity of experiences that make our community so vibrant. It's not just about exchanging business cards — it's about building relationships. The person you chat with might be your future collaborator, mentor, or the missing piece to your team.

Finally, I'm sure you all have noticed that 2024 is a leap year, and of course, that means we have an extra day to complete all of our to-do lists. Unfortunately, we cannot add a day to Photonics West, but I think you can agree that we have added enough to the program and footprint to fill up a day's worth of time just the same. I hope your week is full of inspiring conversations, serendipitous meetings, and fruitful connections. Thankfully, you have a leap day to recover and follow up on all of your Photonics West discussions!

KENT ROCHFORD

How to build an optical quantum computer

In his LASE Plenary, quantum teleportation pioneer, Professor Akira Furusawa, shared details of his quantum computer that's been decades in the making, as well as the start-up company he's set to launch this year.

Back in 1998, an international team of physicists including Akira Furusawa teleported a quantum state of light across one meter, without it travelling through any kind of physical medium. Furusawa, working with Jeff Kimble at Caltech's quantum optics lab, and colleagues from the Universities of Aarhus in Denmark and Bangor, Wales, used a bunch of optics, receivers, and control systems to create quantum entanglement from two squeezed states of light. They then 'transported' these beams of entangled photons from one side of their optical bench to the other. Critically, the team had disassembled and then reconstructed this quantum state with such high fidelity that the community at large agreed this to be the first 'true' teleportation of a quantum state. Results were published in *Science*.

"Our key tools were low-loss optical parametric oscillators, high-quantum-efficiency homodyne receivers, and optical phase control systems," Furusawa tells *Show Daily*. "With these we created Einstein-Podolsky-Rosen-type of entanglement [and other necessary steps] to realize quantum teleportation — it was awesome."

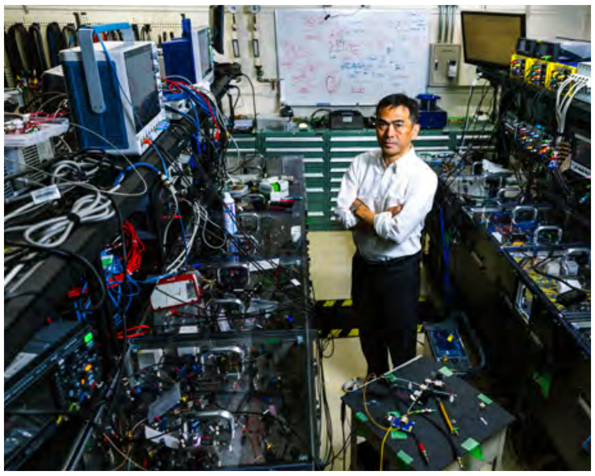
And indeed it was. Before this time only simpler quantum systems, such as a photon's polarization, had been teleported. But by achieving this feat with a stream of entangled photons, Furusawa and fellow physicists had flung open the door to quantum computers, scalable quantum networks and a quantum internet.

Post-teleportation breakthrough, Furusawa returned to Japan, joined the University of Tokyo, and continued to work on quantum teleportation with the lofty goal of eventually building an optical super-quantum computer. Since this time, he and colleagues have been painstakingly constructing the necessary technology to get there — they've nearly made it, and here's how.

Step by step

Six years after his first teleportation breakthrough, Furusawa extended two-way quantum teleportation by building a three-way experimental network based on the quantum entanglement of electromagnetic states. Then, by 2009 he had developed a more complex teleportation network of nine entangled optical beams, and was heading towards the large and critical 'continuous-variable cluster state' over which computations can take place. "We'd realized quantum error correction for continuous variables," he highlights.

Furusawa's Tokyo University team then joined forces with Elanor Huntington and colleagues from the University of New South Wales, Australia, and made worldwide headlines in 2011 when they teleported wave packets of light — across bandwidths up to 10 MHz — in a Schrödinger's cat state. Key experimental steps were to construct broadband, zero-dispersion apparatus that could work with time-resolved equipment to deconstruct light wave packets into a continuous stream of infinitely small time bins for teleportation at high bandwidths. As Furusawa recalls: "We'd succeeded in broadening the bandwidth of our quantum teleportation systems — and in particular had created broadband squeezed light."



Professor Akira Furusawa, University of Tokyo, is edging very close to realising a room temperature quantum computer. Credit: Furusawa, University of Tokyo.

Within a few years, Furusawa and colleagues had honed their time-resolved broadband teleporter set-up to efficiently transfer several entangled photonic qubits. Then, working with Nicolas Menicucci, now at RMIT University, Melbourne, Australia, the Tokyo University team swiftly scaled-up entanglement by multiplexing light in the time domain, generating massive continuous-variable cluster states containing more than 10,000 entangled wave packets of light. Teleportation-based quantum computing was tantalizingly close.

As Furusawa, Menicucci and colleagues wrote in their 2013 *Nature Photonics* paper, 'Ultra-large-scale continuous-variable cluster states multiplexed in the time domain': "The time-domain multiplexing approach allows each additional quantum mode [individual wave packets of light in two beams] to be manipulated by the same optical components at different times, which is a powerful concept."

But while the team's 10,000-plus entangled wave packets had formed by far the largest entangled-state ever created — at the time — a mighty one-million-mode continuous-variable cluster state was achieved in 2016, with a large-scale universal continuous-variable cluster state following in 2019. In this latest experimental set-up, laser beams were directed onto four optical parametric oscillators to produce squeezed light states, which were then woven together by beamsplitters and optical delay lines into the gigantic entangled continuous-variable cluster state.

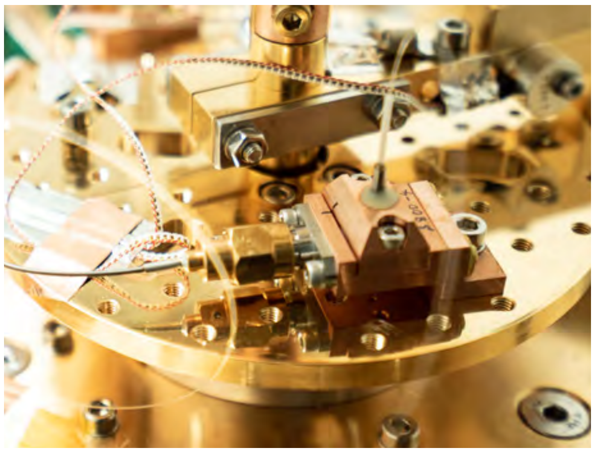
Size is everything in Furusawa's measurement-based quantum computing as the number of entangled wave packets of light, and their entanglement, determines the resource space available for calculations. Researchers' analyses indicated that their cluster state was certainly entangled enough for quantum computation and they were edging ever-closer to the much-coveted 'fault-tolerant' computing that avoids the cascade of errors that can thwart quantum calculations.

continued on page 11

Furusawa continued from page 09

Lighting up quantum processing

Continuous-variable cluster states are not the only route to quantum computing. For years, quantum computing mostly relied on either superconductor circuits or trapped ions to create qubits — the all-important units of quantum information. Superconducting qubits are under development by the likes of IBM, Google, and Canada-based D-Wave while Honeywell, IonQ, and others are pursuing the trapped-ion approach. For each set-up to function and fault-tolerant computing to be achieved, the qubits must be isolated from environmental noise, under cryogenic or vacuum conditions, to reduce errors and prevent the quantum state from collapsing.



A superconducting nanostrip photon detector developed by Akira Furusawa and colleagues as part of their experiments to generate Schrödinger cat states in 2022. Credit: Kan Takase, University of Tokyo.

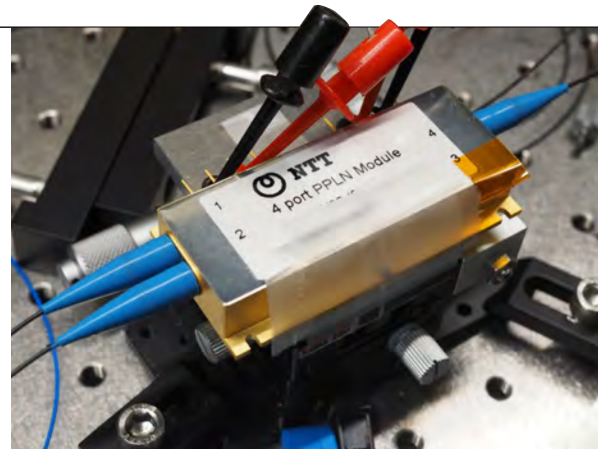
Optical approaches are different, and can be run closer to room temperature. For example, PSIQuantum, has been working with GlobalFoundries on single-photon qubits, based on silicon photonic chips. The California start-up recently won funding from DARPA to develop a million-qubit processor for fault-tolerant computing, and a first commercial quantum computer is expected in the next six years.

Likewise, continuous-variable cluster state quantum computing, as pursued by researchers, such as Furusawa, and start-ups, including Xanadu of Canada, is amenable to room temperature operation. However, proponents also believe these cluster states, which are used for quantum calculations instead of photon qubits, are easier to produce at scale compared to the single photon set-up. Indeed, for Furusawa and colleagues, progress has been undeniably swift and ambitions are growing — as Furusawa described in his Plenary Presentation, ‘Optical quantum computers with quantum teleportation’, on Monday at Photonics West..

In short, the researchers now intend to combine their optical quantum teleportation breakthroughs with wireless network technologies, to build a ‘real machine’ of optical quantum computers. Results from just last year, revealed how Furusawa and colleagues from NTT Device Technology labs and the RIKEN Center for Quantum Computing, exploited their time-domain multiplexing approach to quantum entanglement, to get ever-closer to large-scale and high-speed quantum processing for fault-tolerant computing. The researchers combined a broadband balanced photodiode, typically used in commercial coherent wavelength-division multiplexing (WDM) telecommunications in 5G networks, with an optical parametric amplifier to squeeze and entangle broadband light enough to generate a cluster-state for quantum calculations.

‘A kind of quantum teleportation’

In his Plenary, Furusawa highlighted how next-generation telecom tech — including 6G networking components — can be harnessed to deliver a powerful, ultrafast, multi-core optical quantum processor — which is what he is building right now. The quantum computer set-up will include waveguide optical parametric amplifiers to create 10 THz bandwidth squeezed light, 100GHz-bandwidth 5G/6G technologies and WDM, and non-linear feed-forward. The aim is to achieve, as Furusawa says, ‘a kind of quantum teleportation with 10 THz bandwidth this year’, and then work on the 100 GHz clock, 100-multicore super quantum computer. “The computer will work at room temperature and we should realize it within the next ten years,” says Furusawa. “It should be faster than a conventional computer that has a several GHz clock frequency.”



The waveguide optical parametric amplifier (OPA) module developed by Akira Furusawa and colleagues — they combined this with a photon detector to squeeze and entangle broadband light as part of their experiments to generate Schrödinger cat states in 2022. Credit: Kan Takase, University of Tokyo.

To commercialize this technology, Furusawa also intends to launch a start-up later this year that will eventually provide large-scale ultra-fast fault-tolerant optical quantum computers. But first, the new company will develop quantum computers for running quantum neural networks. These powerful networks hold great potential for certain types of big data analysis, and have already demonstrated that they can have a higher capacity and describe more functions than traditional neural networks. Depending on the architecture, the neural networks can also be trained more quickly.

“This year, we will make a real machine [based on an] optical quantum computer with a modest speed, such as 100 MHz clock frequency, that enables a neural network,” says Furusawa. “It should be very efficient, and moreover, when we also use 5G/6G telecommunications technologies, the clock frequency can reach 100 GHz.”

Indeed, Furusawa is eager to convey the value of next generation telecoms tech in quantum computing, as part of his Plenary Presentation. “The most important message in my talk is that importing the excellent 5G/6G technologies to optical quantum computers can realize ultra-fast optical quantum computers,” he says. “The goal of our start-up should be to provide these large-scale ultra-fast fault-tolerant optical quantum computers — but progress needs to be step by step.”

REBECCA POOL

QUANTUM WEST PLENARY

Is this the future of quantum computing?

As Microsoft taps Photonic Inc to build quantum networks and computers, company founder and Quantum West Plenary speaker Stephanie Simmons, tells *Show Daily* what comes next.

Late last year, Canada-based Photonic raised a mighty $100 million in venture funds and joined forces with Microsoft — a key investor — to scale up its silicon-based optical quantum computing architecture. Founded by Quantum West Plenary Presenter, Professor Stephanie Simmons, the start-up is photonically linking spin qubits — manufactured in silicon — to form a scalable architecture that can support quantum networking over telecom wavelengths. Over the next five years, Simmons and Photonic colleagues will work with Microsoft to develop quantum networking and combine their quantum architecture with the tech giant's cloud computing platform, Azure, to deliver scalable, fault-tolerant quantum computers as well as networks. The ways in which we process and analyze data could be about to change.

"I'm just so excited to share, with the world, what we've been doing after years and years and years of letting it cook behind closed doors," says Simmons. "Many have focused on making qubits... but instead of taking this bottom-up approach, we've worked backwards and have taken a look at what is needed from a systems engineering perspective to deliver quantum technology at scale."

At the heart of Photonic's novel architecture lies the all-important 'T centers.' These silicon defects comprise an

(above) Professor Stephanie Simmons of Photonic Inc and Simon Fraser University: "I'm just so excited to share, with the world, what we've been doing after years and years of letting it cook behind closed doors." Credit: Photonic.

unpaired electron spin, one hydrogen nuclear spin, and two carbon nuclear spins

continued on page 15

A spotlight on Quantum West

Be it computing, networks, timing, or imaging, this year's Quantum West hammers home the importance of photons to all things quantum. Plenary Moderator, Miles Padgett, tells *Show Daily* why he's looking forward to this year's conference.

Now in its third year, Quantum West will be opened by optical momentum pioneer, Miles Padgett, Royal Society Research Professor at the University of Glasgow, Scotland, and member of the SPIE Board of Directors. Padgett has always been fascinated with shaping light beams, and from the 1990s has used lasers to trap microparticles, image beyond classical limits and most recently, to create endoscope-type instruments, only the width of a human hair.

(below) Royal Society Research Professor at the University of Glasgow, Miles Padgett, will introduce the Plenary Presentations at this year's Quantum West. Credit: University of Glasgow.

Padgett will moderate this year's Quantum West Plenary session, which attracted a large crowd on Monday, and included presentations from some of the community's finest scientists. JILA's Professor Jun Ye, quantum pioneer of atomic clocks so precise that they neither gain nor lose one second in some 15 billion years, took center-stage first to chart his breakthroughs. Ye was followed by silicon quantum technology developer, Professor Stephanie Simmons of Simon Fraser University — the start-up she has founded, Photonic Inc, recently won $100 million and joined forces with Microsoft to commercialize quantum computing and networks.

Quantum optics forefather, Professor Marlan Scully from Texas A&M, Princeton and Baylor Universities, closed the session by looking at quantum mechanics in biology, including quantum coherence in brain microtubules. As Padgett comments: "I'm dead curious to hear what Marlan has to say about quantum theory applications in biology — he's a smart researcher who's made a career of thinking differently and I'm sure there's going

continued on page 15

Simmons continued from page 13

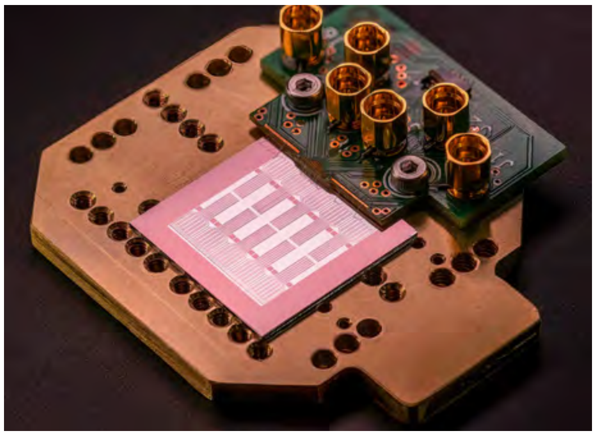
— each of which serves as a qubit and emits light at telecom wavelengths under a magnetic field. Critically, this means these telecom-band qubits can optically link with each other on the same chip and between multiple chips to form the large quantum-entangled states necessary for the quantum processors, computers, and networks of tomorrow. As Simmons highlights: "Essentially, we can have input/output for every qubit — which is wild."

At the same time, these highly connected qubits allow sophisticated error correction codes to be implemented across the quantum architecture to help maintain entanglement and ultimately provide even more system scalability. "Thanks to our high connectivity, we can use these super-efficient, low-density parity check error-correcting codes," points out Simmons. "We've made the prospect of error correction 20 years closer — and this is one of the reasons why we've attracted the funding we have."

Finding the T center

Simmons first became interested in color centers, of which the T center is just one example, back in 2015, when she joined Simon Fraser University as Assistant Professor. At the time, many researchers were working with silicon carbide, but she was keen to explore the potential of these point defects in silicon to exploit CMOS semiconductor economies of scale. "I don't know why, but the whole industry had assumed that you couldn't get these color centers working in silicon," she says.

Simmons quickly determined that selenium impurities in silicon emitted at mid-infrared wavelengths, discovering the T center and its 1326 nm telecom wavelength emission a few years later in 2020. "The selenium results led to me finding the telecom color center, which we now see as this magic center of our entire quantum architecture," she says. "When your silicon qubit can communicate by emitting photons in the same band used in data centers and fiber networks, [you can use this] to connect the millions of qubits needed for quantum computing — the T center is truly magical."



Photonic Inc can pack 1 million qubits into its silicon-based photonic chips. Credit: Photonic.

Simmons and colleagues haven't yet reached the many millions of qubits demanded for quantum processing at scale, but are getting close. A *Nature* publication in 2022 detailed how they had fabricated more than 150,000 unconnected qubits onto an industry-standard silicon-on-insulator integrated photonic wafer silicon chip, and according to Simmons, they have since raised this remarkable figure to a million. "I carry one of these [modules] with a million unconnected qubits in my purse," she laughs. "But the whole point is we shouldn't be constrained to making a 'box' — we've got to find a way of doing the system design for these quantum technologies."

Enter Photonic's latest $100 million funds and Microsoft collaboration. In the coming years, Photonic and Microsoft will be working on the quantum infrastructure system that will eventually achieve distributed entanglement over long distances to deliver quantum communication and a global quantum internet. The partners will initially deliver entanglement between two separate quantum chips — which host T centers, interconnects, optical cavities, photonic switches, and single photon detectors — using telecom fiber. From here, they will build a quantum repeater, that will reliably entangle and store quantum data for a short time in order to create entanglement over large distances. And then, a reliable, fault-tolerant quantum repeater will be built to form the quantum internet.

Still, Simmons remains realistic on the possible hurdles that lie ahead. "There's a lot of detail to look at including scaling controls, the homogeneity of the quantum environment and still squeezing as many qubits as we can in each single [chip]," she says. "I'm not going to trivialize the work that needs to be done, and clearly, there's also going to be unknowns — we're working with new qubits — but I see no fundamental barriers any more between what we have and large-scale, scalable, fault-tolerance."

Plenary points

Simmons was speaking at the Quantum West Plenary session on January 29, in which she took attendees through different silicon color centers and how these can be integrated into silicon photonic chips at scale. She also took a look at what

continued on page 29

Padgett continued from page 13

to be exciting new ideas here."

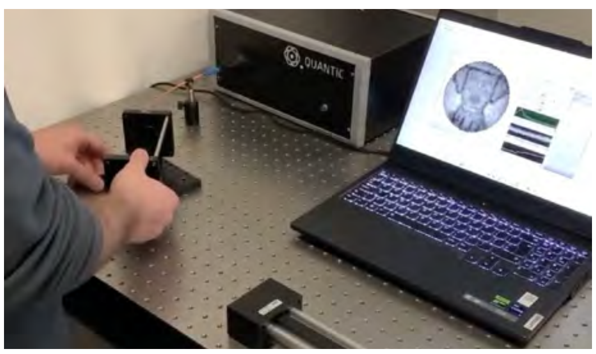
"I think the fact that we've attracted all of these world-leading researchers and 'quantum household names' is a real endorsement to Quantum West," he adds. "It's fantastic to be hearing from the researchers that have created this field and it's going to be a privilege to introduce them all."

Beyond the plenaries

As well as the Quantum West plenary presentations, Padgett is excited about the SPIE Photonics West Exhibition, which runs from January 30 to February 1. With more than 1,300 exhibitors, this year's event will showcase a huge range of suppliers and products.

"I love the exhibition and I would say most of my buying decisions are massively informed by what's on show," says Padgett. "You see all these products in the same space, and this inspires you to think 'there's a new detector — what might I do with that' or 'that's a different way of projecting light — how might I use it?'."

Throughout the exhibition, new detector technologies will be at the forefront of Padgett's mind, and he's looking to learn more about the efficiency and fidelity with which single photons can be detected. A case in point is Hamamatsu's Orca-Quest qCMOS camera that can image quantum phenomena such as duality, superposition and quantum entanglement. "This actually sees and counts single photons — detector technology is now so good that we can do this," points out Padgett. "Seeing these new technologies is a reason that I'm so excited about the exhibition."



Miles Padgett is also the Principal Investigator of QuantIC, the UK's Center of excellence for research, development and innovation in quantum enhanced imaging. Credit: QuantIC.

Padgett also points to the promise of single photon avalanche photodiodes (SPAD) array cameras where each pixel is its own SPAD detector. These cameras can serve as direct time-of-flight sensors in 3D imaging for facial recognition and situation awareness in autonomous driving, with systems launched by Sony, Canon, Axiom Optics, Photon Force, and other optics players.

"All of this detector technology is just fascinating," he says. "At the end of the day, most of the experiments in my research group use products that are bolted together, hopefully in interesting ways, so having an awareness of what all these amazing companies have made can trigger new research ideas."

As well as introducing the Quantum West plenary presentations, Padgett — and members of his research team — will be walking conference attendees through their latest developments. 'Enabling single photon imaging at kHz frame rates using digital holography' on January 28 shows how they can use coherent detection gain through digital holography to eliminate detector noise and image single photons at kHz frame-rates. Meanwhile, 'Transmission of hidden images within noise' on January 30 takes a look at image transfer over free-space using a photon-pair light source that emits two correlated beams.

Padgett himself will be introducing attendees to the latest version of his team's single-fiber endoscope — only the width of a human hair — in 'Imaging through a single multi-mode optical fiber at low photon flux'. As part of the set-up, an input laser beam is shaped to create a scanning spot at the output of the single fiber, which scans the area of interest while fiber also collects and times the backscatter photons to reconstruct 3D images. Results were published in *Science, 'Time-of-flight 3D imaging through multimode optical fibers',* in 2021, and Padgett and colleagues have since been honing the system's signal-to-noise ratio to improve image contrast and also increasing fiber flexibility so imaging can take place without recalibration.

"Our system will initially find application in industrial and environmental inspection, and we've just won UK government funds to make an industrial prototype," says Padgett. "We're now going to make a number of rugged prototypes that potential end-users can play with."

An eye on quantum computing

When it comes to commercializing quantum technologies, Padgett is also

continued on page 29

PHOTONICS WEST SHOW DAILY

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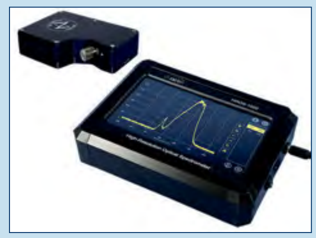

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Silicon photonics expands from its datacoms roots into new markets

Roel Baets, professor at Gent University and imec, Belgium. He is pictured by the clean room facility where his group develops micro-transfer printing. Credit: U Gent / imec.

Over the past 20 years silicon photonics has made a successful transition from academic research field to industrial ecosystem. Transceiver products are thriving in the market. Industrial foundries offer mature process flows and process design kits (PDKs). EDA-companies (electronic design automation) offer photonic IC design tools. Nevertheless, in many ways, silicon photonics remains a small niche field in the semiconductor industry.

Meanwhile, both the research community and a multitude of start-up companies are preparing the next wave in silicon photonics, with scientific achievements and innovative products in a dozen new applications and markets, some of which may become large volume. The value proposition is clear. But the diversity of applications requires new functionalities and new – more heterogeneous — process flows. Will the business proposition follow and become sustainable?

These developments and questions were considered in the OPTO Plenary on January 29, by silicon photonics expert Roel Baets, who is an emeritus full professor at Gent University and imec, both located in Belgium. For many years Prof. Baets has made contributions to research on integrated photonics (silicon, silicon nitride, III-V) and its applications in datacom/telecom as well as in medical and environmental sensing. He has founded and has chaired ePIXfab, the European Silicon Photonics Alliance. He is a Fellow of IEEE, EOS and Optica. He has been recipient of amongst others the 2020 John Tyndall Award and the 2023 IEEE Photonics Award.

He told *Show Daily*, "The overall aims of the plenary talk are to discuss the enormous value proposition of silicon photonics for applications and markets beyond transceivers, but also to discuss the techno-economic challenges involved including my thoughts about the best way forward. My aim is to make the community more aware of the strengths and the opportunities, but also about the threats. I believe it makes sense to try to put noses in the same direction.

"Attendees can expect to learn how we should deal with new SiPh applications of high value that require substantial process flow investment; and how we should deal with new SiPh applications of high value that are not geared towards high volume anywhere soon."

Diverse new market opportunities for the previously datacoms-focused SiPh include the likes of optical gyroscopes, mid-infrared spectroscopy, AI and neuromorphic applications, quantum technologies, chemical analysis, lidar, and diagnostic sensing systems. What is important to enable these diverse applications is the integration with silicon of different materials (semiconductor and other) that enable new photonics applications. "That huge diversity is part of the promise and part of the challenge," said Prof. Baets.

In relation to SiPh, Prof. Baets wears two hats: he is involved in the Photonics Research Group at Gent University, which is also associated with imec. In Gent the research group consists of over 100 people working in the field of silicon photonics. A notable capability of his research group at Gent and at imec is heterogeneous integration by micro-transfer printing. Baets' second role is with ePIX fab, which is the European silicon photonics alliance, which he chaired for many years.

He commented on the growing diversification of SiPh application areas: "The simple story is that if there could be one type of silicon photonics for all the application cases that people are now considering then matters would be relatively simple both for large-volume and small -volume customers. If one looks at the mainstream commercial uptake of this field, high bit rate, high capacity transceivers are obviously the main product of silicon photonics in the market today and they rely on similar forms of manufacturing, enabling passive waveguides and high-speed modulators and detectors in germanium."

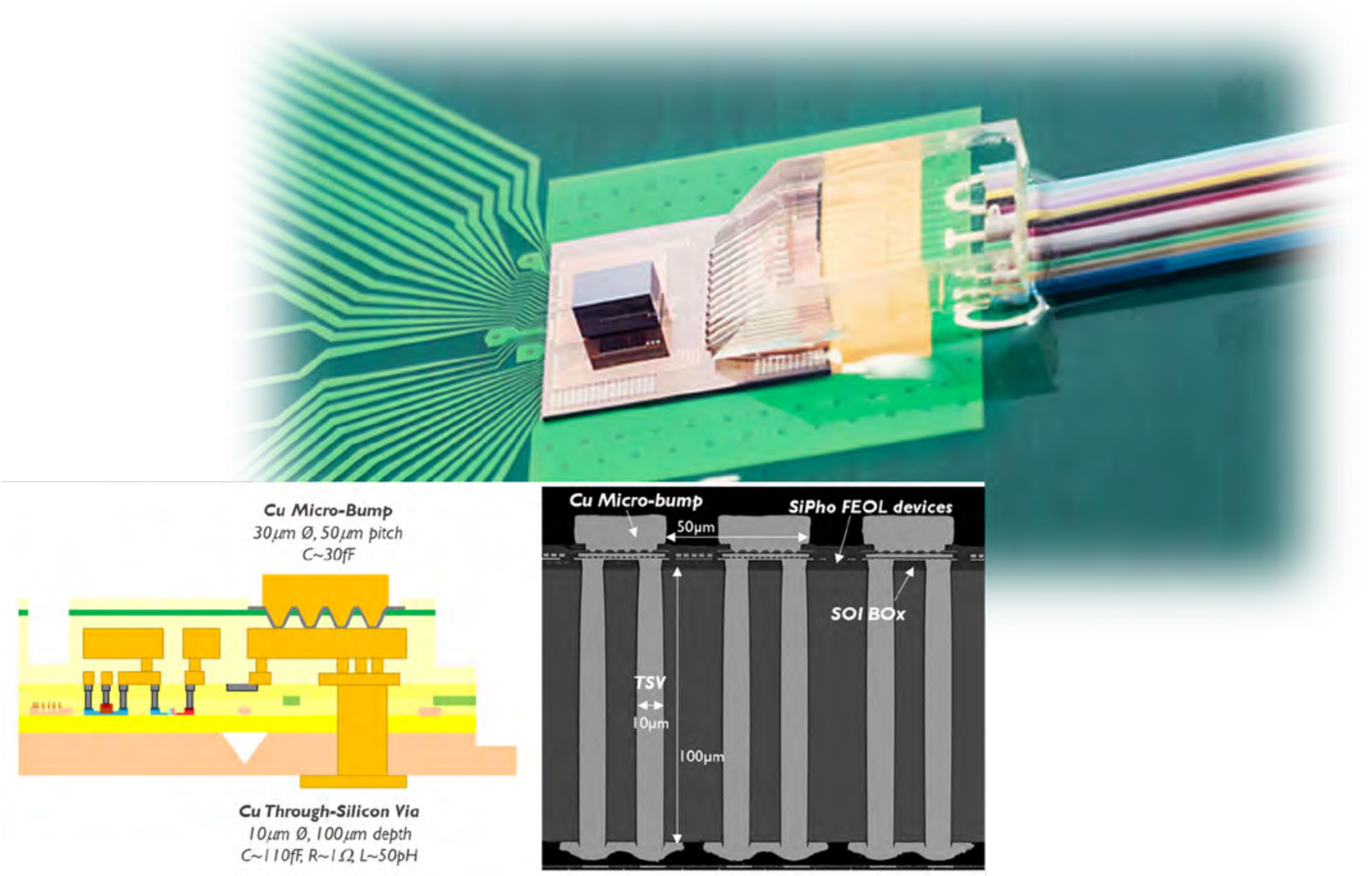
It is because of this diversification, argues Prof. Baets, that the sector needs additions to existing processes. "Some people even dream of entirely different process flows in silicon photonics," he said, "but the big challenge is to bring up new process flows in an industrial foundry environment."

He added, "Many of those new applications are being explored by the research community but also by new start-ups that live under venture funding. So I think I recognise the mismatch between what it takes to bring on stable, mature process flows for these new variations on a theme and the market potential. The value proposition is clear but of course to make it work in a techno-economical context is a big challenge. In my plenary talk, I want to first of all spell out this challenge. I think that is being done too little."

Commercial position and expectations

Considering the commercial potential of the non-telecoms SiPh market, Prof Baets is cautiously optimistic: "In the long run, it will be easier when there will be sufficient volume to sustain the whole operation of manufacturing along the complete supply chain," he said. "That means not only the chip-making but also from design and TDA and through to packaging and testing."

He added, "The long-term picture is sort of rosy, but it's not obvious that there is sufficient financial capability to get through the gap. For a while the volumes will be small meaning that revenue for the fabs will be small. But somebody will have to invest heavily in developing stable process flows with all



Technological progress in the imec silicon photonics platform. Building the next generation of imec's silicon photonics platform in a 300mm fab, enabling 193nm immersion lithography and Through Silicon Vias (TSVs) with low parasitics for symbol rates beyond 100 GBaud. Credit: U Gent / imec.

its associated machinery."

What triggered the market to diversify beyond telecoms? Prof Baets said there is a clear explanation for this, which started a few years ago: "It's quite simple. The first thing is the existing market – in the transceiver case, people want to move onto higher speeds and lower power consumption. Already, the mainstream SiPh platforms have run out of steam. Rates up to 50 gigabaud are now mainstream for SiPh. Of course, there is always demand for more throughput, so users and system developers want to move up to 100 and 200 gigabaud. Those rates are not yet mainstream, so developers are looking in different directions," he said.

Prof. Baets continued, "Over the past two years or so there have been several independent demonstrations of 100 gigabaud and more. Intel, for example, demonstrated such at OFC 2023 and there are a few academic groups who have also achieved that rate. In parallel with that, other groups are already thinking beyond 100 gigabaud. I think most people will agree that using the normal carrier depletion-type plasma dispersion modulators in silicon photonics will indeed run out of steam.

"Then you will really want to move to a proper electro-optic Pockels modulator and that's where lithium niobate, barium titanate, and other materials come in. We are already seeing quite a dynamic scene around the world of various groups using different routes; there is the BTO route, in which IBM has been successful; it has a spinoff developing that approach. With lithium niobate, there are several companies developing platforms based on that material."

Wavelengths beyond communications

When the field of silicon photonics revolved around fiber optics, most development and commercial attention focused on singlemode fiber optics, particularly that supporting the C-band (1530-1565nm) and O-band (1260-1360nm) ranges of wavelengths. As the focus moves from communications into sensing, for example, the need arises to support other wavelength ranges.

Prof. Baets explained, "You really want to move either in the direction of the visible, for example, in the fields of lidar and biosensors, and for other applications you want to move towards the mid-IR, such as applications in vibrational spectroscopy, meaning chemical sensing."

Besides the needs for higher speeds (and lower power demand), and new wavelength bands, there is a third objective that SiPh innovators like Roel Baets are seeking: to integrate the light source on the chip. "With classical SiPh you don't have an integrated light source," he said. "But now there are already a few examples where integrated light sources have achieved industrial maturity; the best known case is, of course, Intel's transceivers, in which they have the integration of bonded indium phosphide multilayer stacks and the processing of lasers, SLEDs or SOAs onto the same platform."

Micro-transfer printing

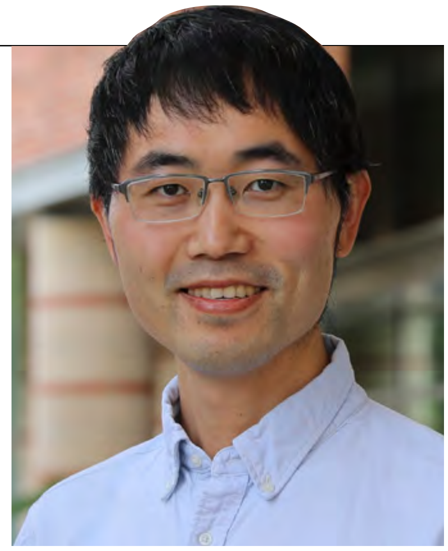
A new approach, which is one of the focus areas of the UGent research team – and part of his plenary presentation – is micro-transfer printing. He explained, "A prominent technology gaining a lot of traction today is micro-transfer printing; a well-known technique already employed for micro LED integration, is now also being used in enhancing photonic integrated circuits, with, for example, a finished DFB laser or a semiconductor optical amplifier (SOA)."

"In my presentation, I will be advocating heterogeneous integration techniques, and micro-transfer printing is one example, that minimize the complexity

continued on page 27

AI-enhanced processing promises boost for biomedical imaging

New conference series at Photonics West to chart the rapid progress and potential of smarter, computational imaging.



Conference chair: Prof. Liang Gao, Associate Professor at UCLA's Samueli School of Engineering. Credit: UCLA.

The growing importance of the interface between computational optical imaging and AI for biomedical applications is addressed by a series of more then 80 presentations which took place at Photonics West between January 27-29 under the umbrella title of Computational Optical Imaging and Artificial Intelligence in Biomedical Sciences.

We're looking at whether the AI-based computational advances in vision and graphics can be introduced into biomedical imaging fields to solve the current bottlenecks.

Prof. Liang Gao, Associate Professor at UCLA's Samueli School of Engineering, who is also one of the conference Chairs, told *Show Daily* about the rise of this sector and then pointed out some of the program highlights.

"This is a new conference. In recent years there has been a hot trend in bringing AI-assisted technologies into the biomedical imaging," he said. "We're looking at whether the AI-based computational advances in vision and graphics can be introduced into biomedical imaging fields to solve the current bottlenecks."

Advances in high-resolution microscopy, including computational imaging microscopy, have enabled especially high resolution, large field of view imaging. At the same time there have been huge advances in AI-based algorithms for biomedical image analysis. This combination is the background to the new Photonics West conference — "to bring together experts from different fields to brainstorm the next 10 years for this field," said Prof. Gao.

A related issue is that while the technical performance of lenses and optical hardware may have reached a limit, imaging results can still be improved by using algorithms to enhance the image. Prof Gao added, "We can improve biomedical images even more by using AI to capture and then predict better results."

In constructing the new conference program, the panel of chairs, which also included Guoan Zheng from the University of Connecticut and Seung Ah Lee from Yonsei University (Korea), has chosen a variety of topics spanning components, AI-driven hardware designs, and computational optical imaging, and, especially the interface between hardware and software.

"There are many research groups looking at these areas, trying to integrate the AI-designed optics into hardware. Their aim is that the AI-integrated hardware can achieve a much better performance than before," said Prof. Gao.

Key speaker: Prof. Aydogan Ozcan. Credit: UCLA.

Certain groups in this field are trying to replace certain parts of AI with hardware in order to perform optical computing more rapidly. This has been pioneered by Aydogan Ozcan's group at UCLA; Prof. Ozcan is a keynote speaker in the conference.

Prof. Ozcan's significant presentations included: Diffractive optical networks enable quantitative phase imaging through random, unknown diffusers; Diffractive visual processors (keynote); and Light-field tomographic fluorescence lifetime imaging microscopy.

Accuracy of enhanced images

A key question in this field is, if the quality of a biomedical image is enhanced by using AI software, how can a researcher be confident that such a software-generated image is an accurate representation of the sample under investigation?

Prof. Gao explained, "There are different approaches. One way to make AI-generated medical images representative is to ensure that the AI models get sufficient training datasets so a model generated can be generally appliable to different samples. Also, regarding how to improve the performance of AI, we can potentially build in some hardware components into the software as well. In this way we can not only make the computation faster but we can also save costs on the computational resources."

Besides the research and theoretical approach to this field, does the new conference feature speakers who are working in the commercial side of enhancing biomedical images with AI and software techniques?

Prof. Gao gave some examples, saying that certain speakers do have this knowledge and experience: "For example, Dr. Ji Yi from Johns Hopkins University is speaking on imaging mesoscopic microscopy. His research focuses on computational OCT and he has a huge interest in retinal imaging applications; he will likely talk about how such computational OCT can be applied to human imaging."

Dr. Ji's invited paper is entitled, "Large-scale dynamic imaging by mesoscopic oblique plane microscopy and computational augmentation." Another expert on the commercialization of AI-enhanced imaging is Dr. Lei Li from Rice University, who presented an invited paper entitled "Machine-learning enhanced photoacoustic computed tomography."

A notable speaker from industry was Dr. Shalin Mehta, who is Platform Leader at the Chan Zuckerberg Biohuub, a group on nonprofit research institutes across the USA, that brings together physicians, scientists, and engineers with the goal of pursuing grand scientific challenges with 10-15 year horizons.

Prof. Gao said, "Yet another example of a downstream expert speaking to the conference is Assistant Prof. Roarke Hortsmeyer from Duke University, who is also on the conference committee. He has a company commercializing these computational gigapixel cameras so this is a good example of connecting the research to industry and translating these computational optical devices into commercial platforms."

Prof. Roarke's presentation is entitled, "High-throughput computational microscopy with diffractive multiplexing across a gigapixel sensor array."

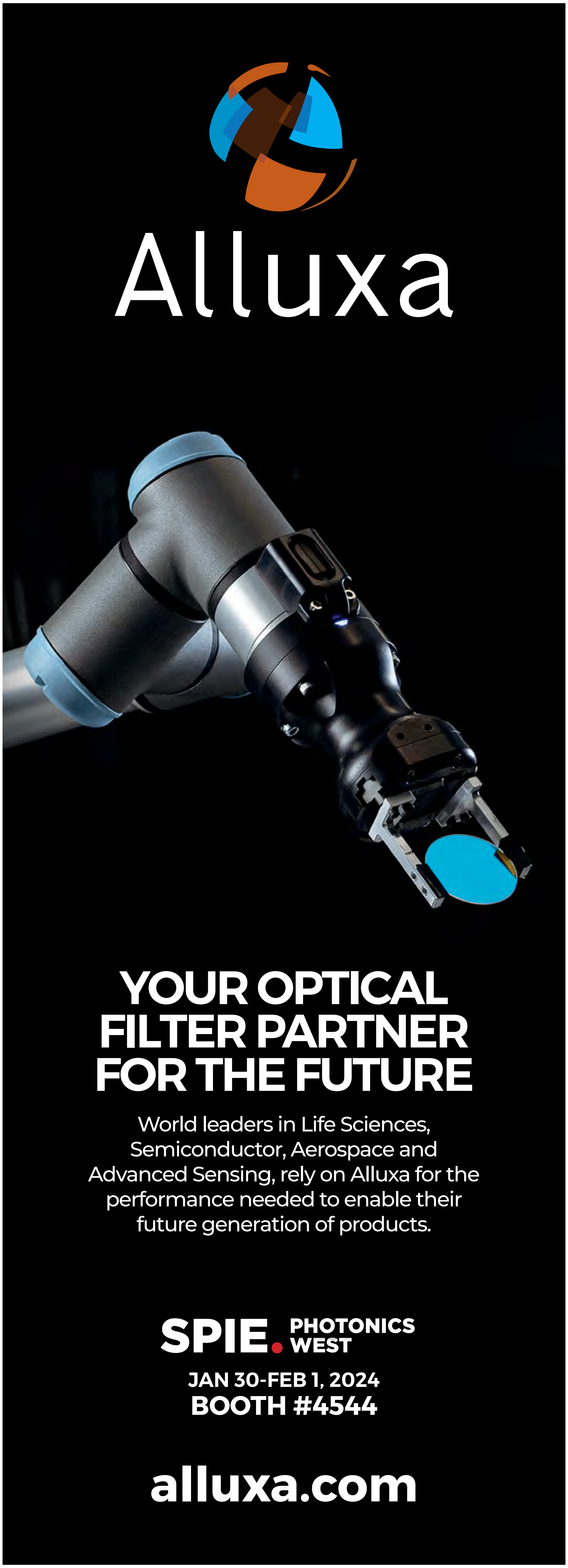
Liang's LIFT-FLIM system to be showcased

Prof. Gao's UCLA group was also the subject of presentations: "It concerns a new computational fluorescence lifetime imaging microscopy technique, based on a collaboration between Profs. Gao and Ozcan on this paper."

LIFT-FLIM will be described in a paper "Light-field tomographic fluorescence lifetime imaging microscopy," presented on January 29 by Prof Gao's student Yayao Ma. The presentation covered some of the enhancements offered by the LIFT-FLIM systems.

Fluorescence lifetime imaging microscopy (FLIM) measures fluorescence lifetimes of fluorescent probes to investigate molecular interactions.

continued on page 23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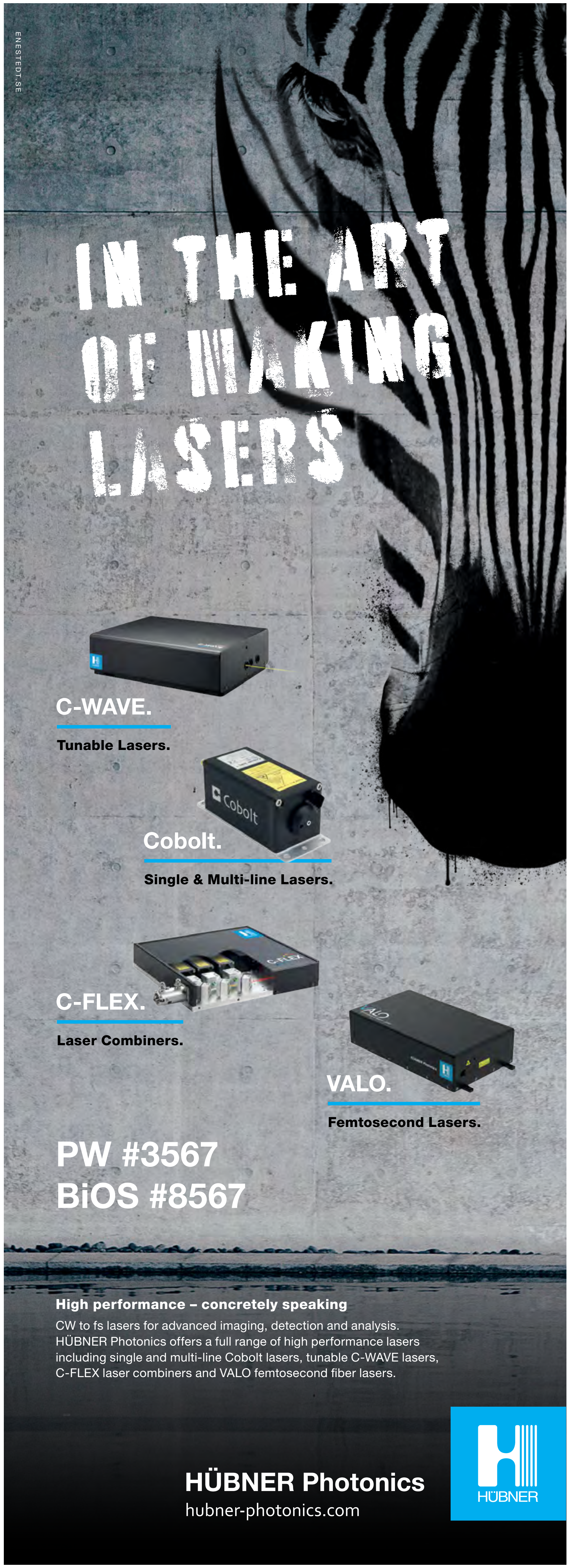
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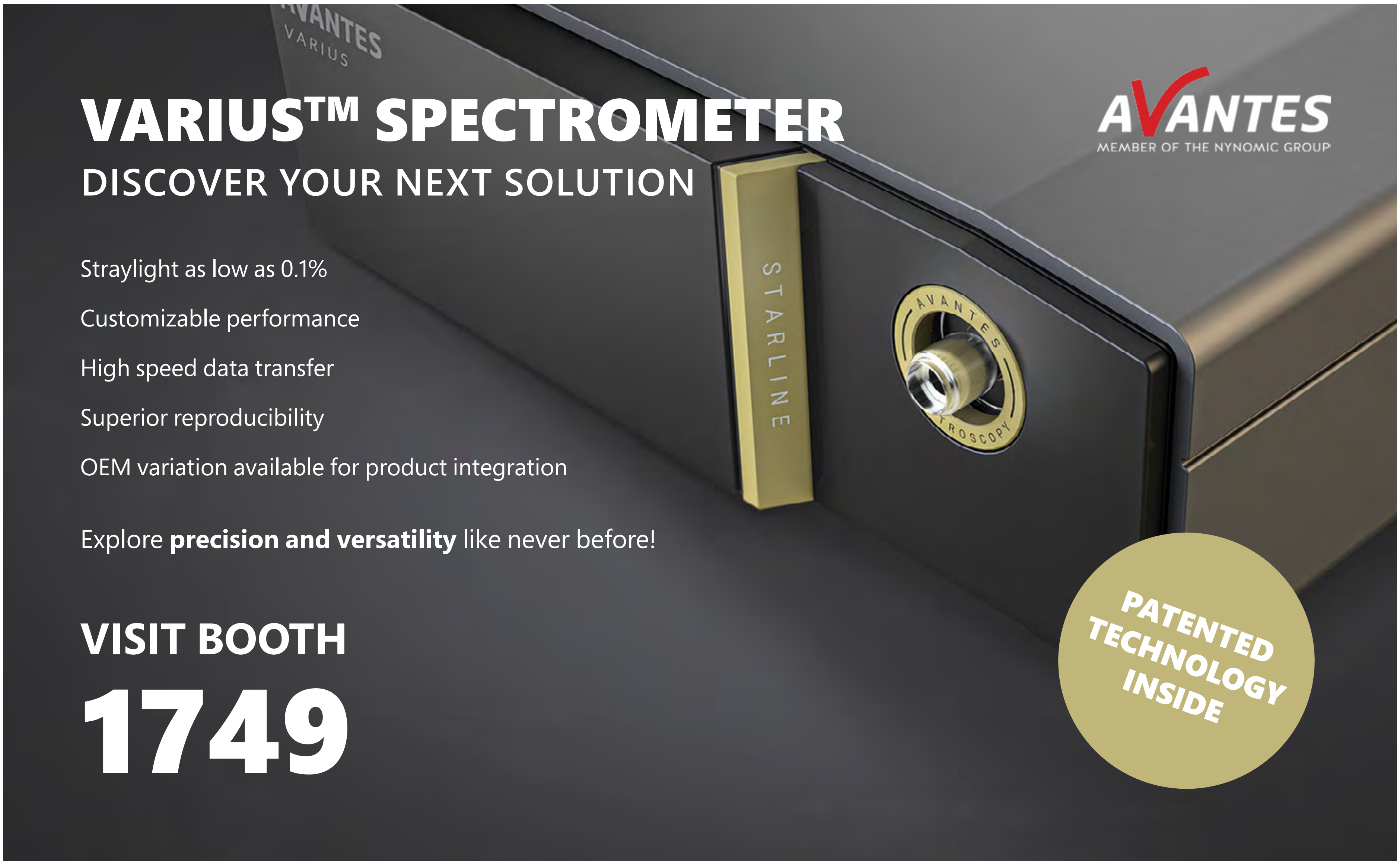
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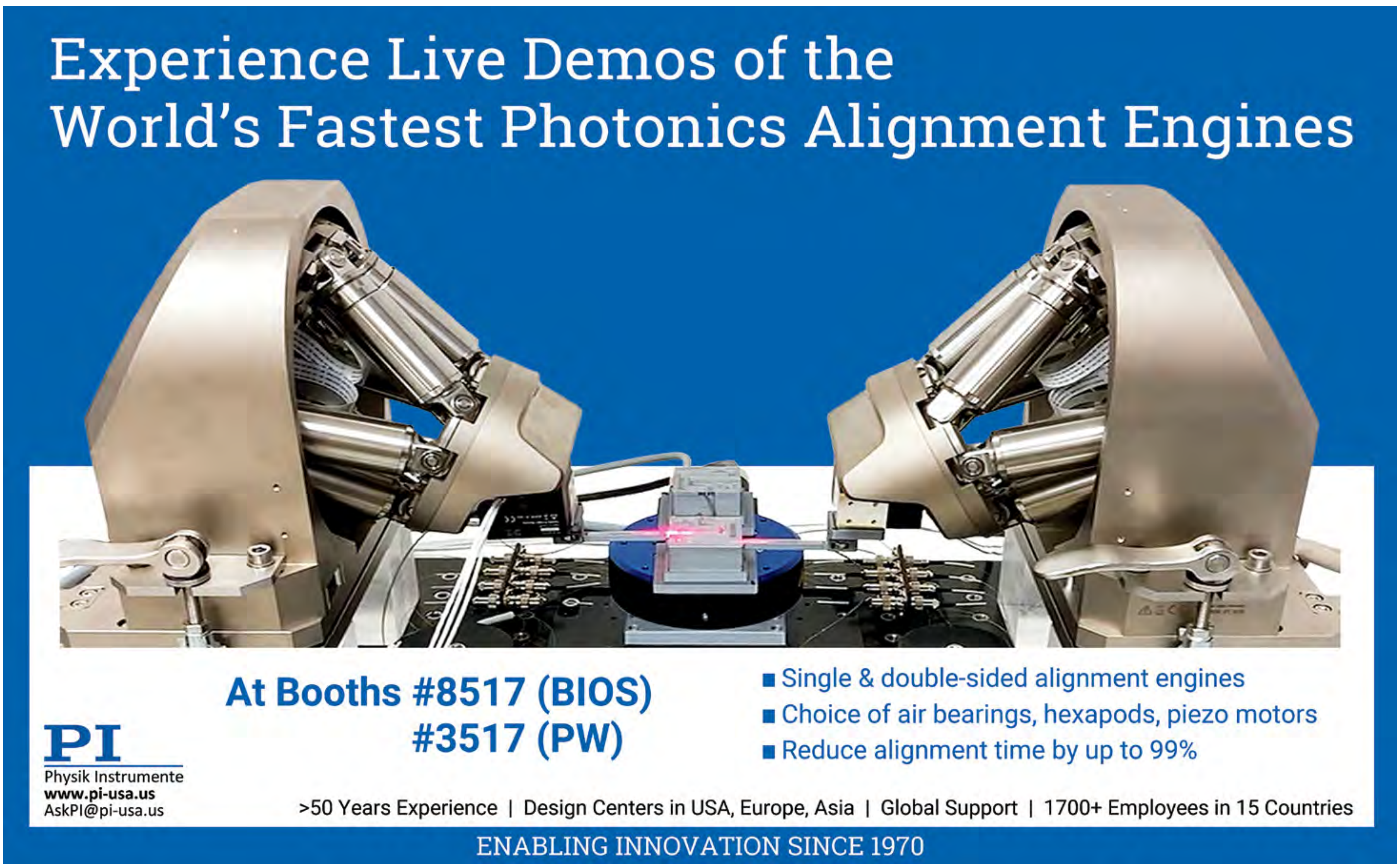
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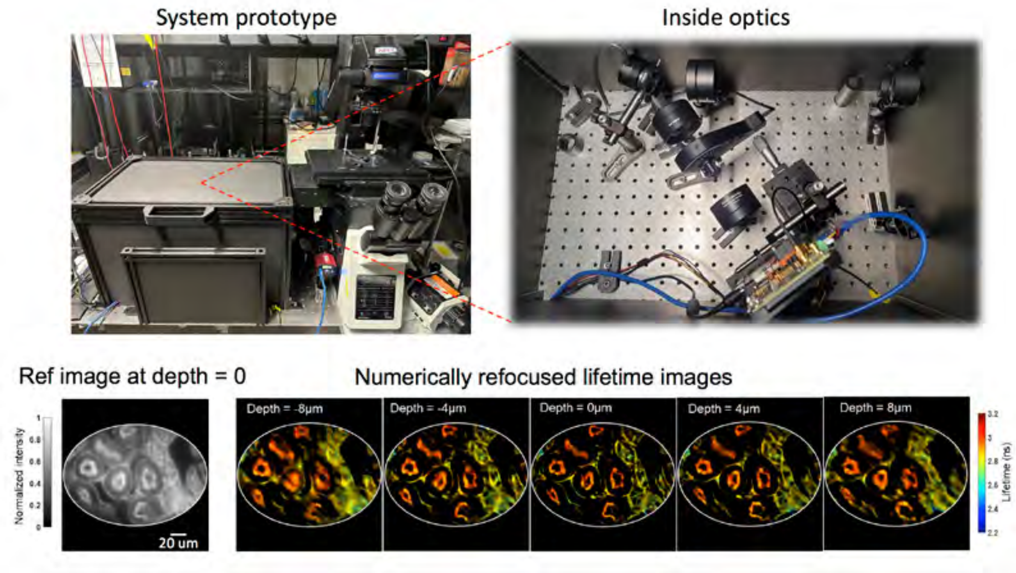

Light-field tomographic fluorescence lifetime imaging microscope (LIFT-FLIM). Imaged examples. Lower left: Cell membrane: Alexa Fluor 488 wheat germ agglutinin (WGA); lower right: Filamentous actin (F-actin): Alexa Fluor 568 phalloidin. Images courtesy of Prof. Liang Gao.

Liang Gao continued from page 20

However, conventional FLIM systems often require extensive scanning that is time-consuming. To address this challenge, Dr. Gao's group developed a novel computational imaging technique called light field tomographic FLIM (LIFT-FLIM). Their approach acquires volumetric fluorescence lifetime images in a highly data-efficient manner, significantly reducing the number of scanning steps and, thereby, remarkably improving the 3D FLIM frame rate.

Prof. Gao explained further, "It's AI-based fluorescence-lifetime imaging microscopy (FLIM). FLIM is a powerful technique in the biomedical sciences, because it can yield functional information instead of just structural information. But its drawback is that it is rather slow — it requires raster scans across three-dimensional volumes — because it has to measure fluorescence decay time instead of only fluorescence intensity.

"So we developed a new approach, which combines light field imaging with AI enabling us to extract three-dimensional FLIM images from only one-dimensional measurements. We're using the line SPAD camera, which has single photon sensitivity.

"We use AI so we can measure these three-dimensional objects. Actually, we call it four dimensional — three spatial dimensions and one fluorescence lifetime dimension. This is made possible only by AI with these computational approaches. They cannot be done by conventional optical approaches, so this is one example of why AI so important to enable new functionalities for bio-imaging."

Potential applications

Prof. Gao explained that one potential end use of this new "4D" imaging process, could be label-free cancer imaging: "In our paper we demonstrate that this method can be used to differentiate normal tissues from cancerous tissues without using any contrast agent — only based on the metabolisms of tissue because cancerous tissues normally have higher metabolic rates than normal tissues.

"This kind of difference can be detected through the fluorescence lifetime. With our approach we can perform this wide field computational imaging, so we can do real time three-dimensional lifetime measurement. Potentially it could be translated to intra-operative imaging, and cancer imaging applications. It can also be used for the high throughput drug screening applications, for which metabolic screening is also a hot topic at the conference in that area as well, for drug discovery," he said.

Commercial routes

With commercialization in mind, Prof. Gao also revealed that in April, 2023, he and UCLA partners had set up a new company, Lift Photonics, in Los Angeles, CA. They are trying to push these technologies from the lab toward the commercial market.

"There is a huge opportunity for AI

continued on page 24

Liang Gao continued from page 23

in this field," he said. "These kinds of devices can be used for analyzing artificial image inflows, so they can accelerate the counting rate and the classification rate of objects of interest."

Similarly, for other microscopy or endoscopy systems, some developers are trying to build in AI into the hardware in order to save the time for later data processing, to generate results more rapidly, which is crucial for this kind of a medical intra-operative imaging applications.

There is also commercial potential in digital pathology because for conventional pathology the turnaround time is slow. While for the AI-assisted optical imaging, the whole process can be significantly accelerated.

"Computational imaging has been widely applied into different areas; it's a mature science in use to investigate these surface chemistries, electron couplings, and those kind of applications. It's also suitable for certain industrial inspections — and remote sensing applications are another huge area for computational imaging," he said.

"In remote sensing we want to capture spectral imaging data set using a computational approach to make this data acquisition more efficient. This is known as computational spectral imaging."

> In medical diagnosis and interventions, the tolerances are very tight, especially if you want to use an AI assistant for operating images for surgery. In that case, a patient's life relies on artificial intelligence so reliability is a big issue.

This topic was described in a paper "Compressive hyperspectral imaging," presented on January 27 by Prof. Gao's student Qi Cui. The presentation covered some of the enhancements offered by computational spectral imaging systems.

So where are these developers and users obtaining their AI software; are they creating it themselves or are they buying off the shelf packages?

Prof. Gao said he believes that most of them are creating it themselves but not developing it from scratch: "They adapt some existing machine learning models from the computational graphic or computer vision fields and adapt these models specifically for biomedical imaging applications. Considering most of the researchers in our field, we are not naturally computational scientists!"

He thinks that generative adversarial networks ("GANs") are probably the most widely used machine learning models being used for this kind of image transformation. Some other groups use it for super resolution applications. For these GAN-based networks, it was originally developed for the motion-vision or fake image detection.

Problems yet to solve

Considering the main problems remaining to be solved in his field, Prof. Gao commented, "For people using AI for biomedical imaging, the biggest bottleneck is how to make the results more reliable. In medical diagnosis and interventions, the tolerances are very tight, especially if you want to use an AI assistant for operating images for surgery. In that case, a patient's life relies on artificial intelligence so reliability is a big issue."

So this is actually one of the huge challenges of the current field — how to make the modelling reliable enough for diagnosis and medical applications and how to make training data sets reliable, so that modelling can be generalized to a more representative population instead of only for a few groups.

"We should consider the introduction of AI or software approach to the hardware designs and constructions. Considering conventional imaging hardware it generates images that are just a replica of the object. But for the new AI assistant approaches, the generated images can be an encoded image, which can be the spatially multiplexed image."

He concluded, "So with some smart AI processing data processing, gathered data can generate more rich information content — to make this whole measurement pipeline more data-efficient — and accurate."

MATTHEW PEACH

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Ready for primetime?

MicroLEDs have plenty of promise, but are they ready to take over for OLED in the marketplace?

Eric Virey, Yole Group. Credit: Yole.

MicroLEDs, like OLEDs, is an emissive display technology in which each individual red, green, and blue sub-pixel is an independently controllable light source. Both technologies bring high contrast, high speed, and wide viewing angles, but thanks to their inorganic makeup, microLEDs could deliver even better colors, contrast, higher brightness, lower power consumption, longer lifetime, and environmental stability and ruggedness.

MicroLED could also allow the integration of sensors and circuits in the future, enabling thin displays with embedded sensing capabilities, such as fingerprint, in-display camera, touch function, gesture control, and more. However, the technology is still immature and microLEDs are complex to manufacture. Of course, further advancements in the basic science surrounding microLEDs will continue, but overall, the science is here and now microLEDs are now mostly a massive manufacturing, engineering, and supply chain challenge.

As part of the Industry Program, on Tuesday, a panel of experts will discuss the readiness of microLEDs in the session, *MicroLED: from Sprint to Marathon?* The session will provide an overview of the status of the microLED industry as well as a focus on the efforts and strategies of two companies with very different profiles: a startup (Aledia) and a technology giant (Intel). Moderating and participating in the session is Eric H. Virey, Ph.D., principal display market and technologies analyst in the Photonics, Sensing & Display division at Yole Intelligence, part of Yole Group. Virey was interviewed by the *Show Daily* prior to the session.

Show Daily: How close are microLEDs to mass production/adoption?

Eric Virey, Yole Group: At Yole Intelligence, we estimate that exiting 2023, the industry has spent about $12 billion on microLED development and industrialization. Another $2.4 billion has been spent on mergers and acquisitions. This still pales compared to the more than $100 billion spent building OLED fabs since the mid-2000s, but still, it shows strong momentum. All display makers now have sizable microLED activities. The first commercial products, various AR headsets and an 89" TV from Samsung, are available. A luxury watch from Tag Heuer is expected in spring. The supply chain is shaping up, and various companies are investing to set up manufacturing.

The elephant in the room is Apple's microLED foundry partner ams-OSRAM which is investing close to a billion dollars in a new 8" microLED fab in Malaysia. Downstream, LG Display will supply the Thin Film Transistor (TFT) backplanes on which it will also assemble the microLED using a proprietary technology developed by Apple and its equipment partner.

Besides Apple/Osram, Taiwanese holding Ennostar is building a 6" fab In China, and most leading display makers have aligned themselves with leading domestic LED makers. BOE spent $300 million to acquire a controlling stake in HC SemiTek, which is using the entire proceeds to build a 6" microLED fab. Sanan is spending close to $2 billion in a new fab with $200 million earmarked for microLED. JBD completed a $100 million, vertically-integrated microdisplay fab near Shanghai. AUO and Samsung have started production of small volumes of smartwatch displays and microLED TVs, respectively. Vistar broke ground on a $413 million microLED display project, and many other companies are setting up more fabs and pilot lines.

Osram's fab, initially scheduled to ramp in 2024, is now expected to start late 2025, and while Ennostar's first phase is on track for mid-2024, the second phase is pushed back 1 to 2 years, to 2026 or 2027. Other projects are also experiencing delays. Apple's smartwatch, the first actual, high-volume consumer microLED product, is not expected to hit the shelves until 2026.

SD: What are the main manufacturing challenges, and how are they impacting adoption?

EV: Making a display involves processing LED epiwafers into arrays of microLED chips poised for transfer and integration into a heterogeneously integrated system incorporating the LEDs, pixel-driving transistors, optics, etc.

Manufacturing an 8K resolution (7680 x 4320 pixels) microLED display implies transferring and assembling almost 100 million microLEDs that are the size of bacteria with a placement accuracy of ±1µm and doing so in less than 10 minutes to be economically viable. Today's LED and die bonders can't manipulate the very small dies required to enable high-volume consumer applications, and, at the necessary level of precision, they typically have throughput in the range of 1,000 dies per hour. At this pace, it would take 11 years to manufacture a single 8K TV. Even recently developed miniLED transfer equipment would require more than a week.

There is, therefore, a need for a paradigm change: the development of mass transfer technologies that can manipulate and assemble much smaller dies and do so at least 5 orders of magnitude faster.

Progress has been spectacular, to the point that many industry players no longer see it as a fundamental roadblock. Only three years ago, a company developing microLED displays had to invent its own mass transfer process and build the equipment. Today, more than a dozen off-the-shelf tools are available from equipment makers.

A correlate to imperfect transfer and assembly is yield cost. With microLEDs, bad (dead) pixels can originate from a faulty die, a missed or misplaced die during transfer, or a defective electrical connection. Today's yield for the mass transfer range from 3N (99.9%) to 5N+, but the yield for the chips themselves, related to epitaxy and chip processing are lower, typically around 99% to 99.5%

At those levels, an 8K TV will still have half a million defective pixels. Manufacturers must, therefore, develop effective yield management strategies combining pixel redundancies and/or individual pixel repair, along with chip and pixel testing and binning.

To limit repair needs, testing and inspections are critical to remove bad dies from the process flow as early as possible. Multichannel probe card testing tools are now available for microLEDs, but in the near future, there could be up to 500 million dies on a single 8" wafer. To test a single wafer, it would take more than 40 hours for the best probers on the market today. For very small, high-density chips, massively parallel, contactless testing is, therefore, a better option.

Overall, these first-generation tools (mass transfer, inspection, testing, etc.) are suitable for development, pilot lines, and, in some cases, for a first product. They considerably lower the entrance barrier for newcomers and significantly accelerate development cycles. Nevertheless, more is needed in terms of yield, capabilities, and costs to enable actual high-volume, cost-effective manufacturing of consumer products.

SD: Is there a scenario where OLEDs can continue to improve and remain the dominant tech? If so, how?

EV: OLED is a moving target. It keeps improving in both cost and performance thanks to better materials, display architectures, manufacturing infrastructure, and massive investment. As OLEDs improve and microLEDs continue to be delayed, microLEDs' value proposition shrinks.

For most applications, it will be challenging to compete on cost. To succeed, microLED must strongly deliver differentiated performance vs OLED while narrowing the cost difference.

Ultimately, at Yole Intelligence, we expect the two technologies to coexist and compete in the high-end segments for most applications.

SD: What applications lend themselves best to microLEDs, and which will be the last to adopt?

EV: There are two categories of applications for microLEDs. In the first group, microLED characteristics intrinsically differentiate and are superior to any other display technology. For those, microLEDs are in a "market pull" situation: OEMs are eager to adopt the technology as soon as it matures enough and reaches a cost compatible with their application. This group includes microdisplays for Augmented Reality (AR) headsets. Here, microLED is potentially the only technology capable of delivering the right combination of size, brightness, cost, and power consumption

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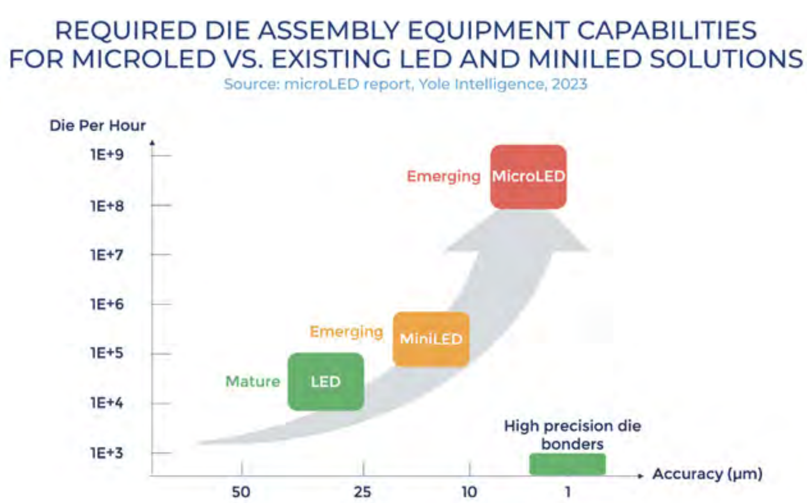


Silicon photonics continued from page 19

and the cost of developing mature manufacturing process flows. It helps when the integration falls back as much as possible on already existing process flows and when the integration happens late in the backend.

"I will be illustrating what I'm talking about with various examples. What we see today is that while micro transfer printing up to not so long ago was mostly an R&D tool, we are now seeing considerable interest from industry and we see traction from the industrial side to really see it as a manufacturing tool and to start developing the supply chain for such a method."

So who is likely be doing this in a possible commercialized future? Prof. Baets said this remains an open question: "Because we would be bringing together wafers from a silicon foundry on the one hand, with wafers from a different III-V foundry, so there could be two different actors," he said. "Who will be the industrial actor taking care of integration? Will that be in the silicon fab, perhaps? "That's one model and I know of at least one case where it seems to be evolving in that direction; or could it be by distinct actors or boutique fabs that are specializing in exactly that."

Relatively small volumes

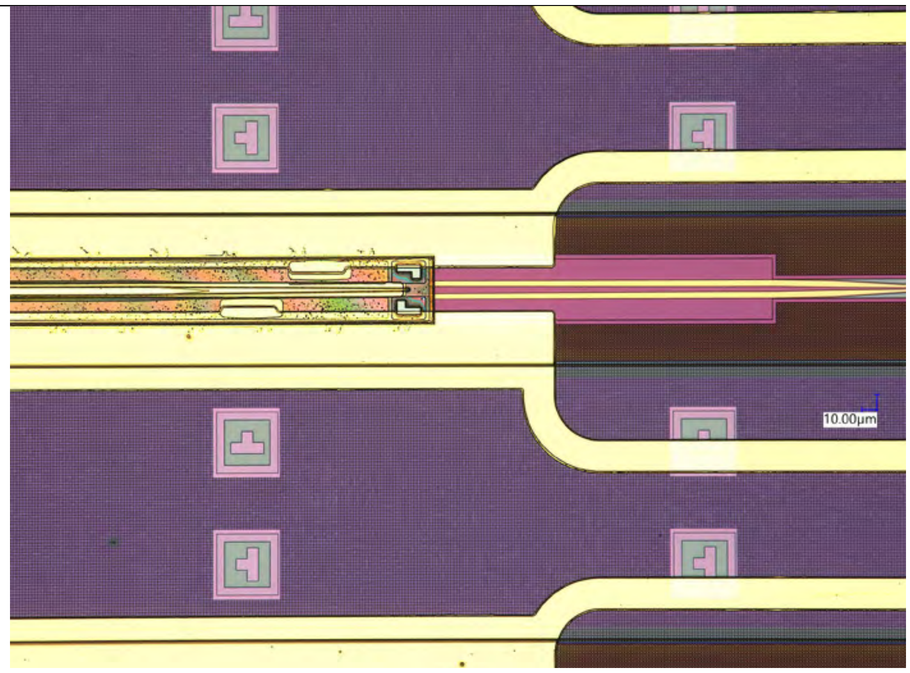
When considering the volume of today's silicon photonics transceiver business, Prof. Baets estimates that there are probably around 5 to 10 million SiPh-based transceivers being manufactured and sold each year. He commented, "From a photonics and a telecoms perspective that is considered to be quite a high volume, but from a semiconductor industry perspective that is small volume. Because if you calculate how that translates to the number of wafers then you come to the conclusion that a major manufacturer, whether GlobalFoundries or TSMC or whoever, would have to run a very small fraction of their capacity to serve all the needs for silicon photonics transceivers in the world today."

He said therefore that, whatever the likely evolution of silicon photonics beyond communications, it will require significant investment and beyond that a great deal of patience by investors and manufacturers before the application volumes become commercially significant — and therefore valuable.

He said, "We can list more than 100 companies today that are developing products based on silicon photonics that are not for transceivers. None of them is yet in the market with any level of scale; some have their products for sale at the moment but they're selling the order of hundreds of them into the market. So the volume today of non-transceiver silicon photonics products going into the market is the peanuts of peanuts! Many of them, unless they can piggyback on the mainstream existing platforms, have not secured a reliable scale-up route for mass manufacture."

Prof. Baets concluded, "What are the positives in this? If somehow we can solve the problem of establishing this scaled-up manufacturing route then the value that we can create eventually remains huge."

MATTHEW PEACH



Heterogeneous integration. Microscopy image of a C-band InP semiconductor optical amplifier (fabricated by III-V Lab) micro-transfer printed on a Si-on-SiN waveguide circuit (fabricated by imec) to make narrow-linewidth tunable lasers. Credit: U Gent / imec.

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Yole

continued from page 26

for the application.

Automotive is another case: automakers are anticipating microLED's potential to deliver a combination of very bright, high contrast, rugged, durable, transparent, conformable, or rollable displays.

For most other consumer applications such as smartphones, smartwatches, TVs, laptops, etc., OLED is already doing an excellent job and continually improves in terms of both cost and performance. MicroLEDs are in a "market push" situation: to compete, it has to deliver strong differentiation and do so at a cost similar to that of OLED.

Achieving this requires strong champions, companies willing to commit vast resources to lead microLED through a long and challenging development path. Examples include Apple with its watches and phones, Samsung with its TVs, and AUO for wearables and automotive. More could emerge: Innolux, BOE, and Tianma are all accelerating their efforts.

SD: How do the market pressures and competition affect the evolution of the technology?

EV: Apple put microLED on the map when it acquired startup LuxVue in 2014. Since then, efforts at all leading display makers and many OEMs have increased exponentially. All display makers now have sizable microLED activities. To a lesser extent, Samsung is also championing microLED with its TV application. The next 2-3 years will be critical: Apple's smartwatch and Samsung's TV projects are incubators for the entire industry. The watch is now expected in 2026, but failure of this effort would be a massive and potentially fatal blow to the industry.

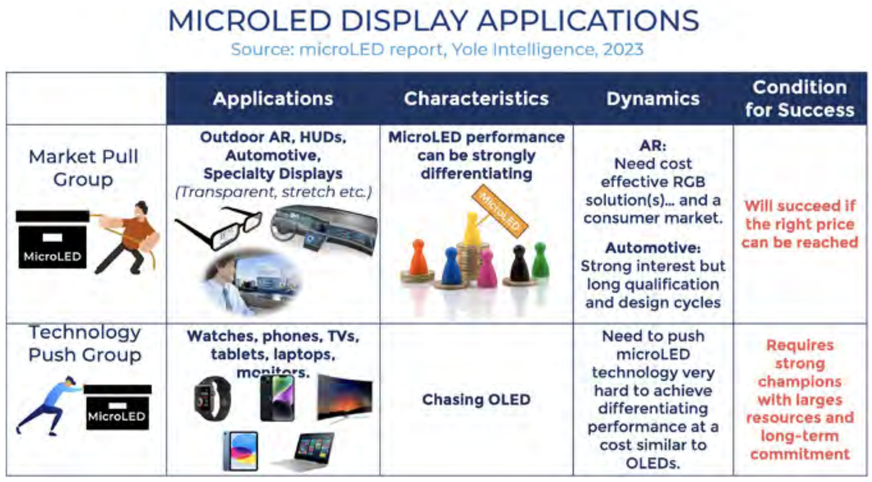
SD: Will success depend on adoption by the tech giants or can newcomers and startups push effectively?

EV: For now, only tech giants have the resources to develop the technology and enable the supply chain. But microLED's supply chain is also much more horizontal and distributed than OLEDs or LCDs. The most recent OLED fabs are vertically integrated from the TFT backplane to the frontplane and full panel. BOE is planning to spend close to $9 billion on a new generation 8.6 OLED fab. Samsung is spending about half that amount for a fab with roughly half that capacity. Very few companies can afford that kind of expense.

For microLED, startups will mainly be technology providers, licensing or selling technology transfers to large display makers or OEMs and tech giants. Down the road, however, the more distributed CapEx and horizontal supply chain could enable new entrants with low CapEx or even fab-less strategies. A company could source the microLED chips from a microLED foundry, microdrivers from a traditional Si-CMOS foundry, have the displays assembled by an OSAT, etc.

This is especially true for AR microdisplay applications, which require lower volumes of wafers and for which most of the supply chain bricks will soon be in place.

KEVIN PROBASCO



ARIA Bale

continued from page 04

confidently to the climate crisis."

Examples could include wavefront shaping to help better determine the composition of clouds, sensing technologies to improve methane detection, and spectroscopy to gain a better understanding of the ability of oceans to act as carbon reservoirs.

"Although we have satellites [observing the climate], there are lots of gaps in monitoring," Bale told attendees at the BiOS show floor panel session. "We need things like better resolution and broader coverage, [because] our models are not accurate enough as a result. Optics and photonics is where some solutions should be."

Bale added that some of the other ARIA programs could also offer funding opportunities for photonics, such as "programmable plants" intended to improve food security, or minimally invasive technologies capable of interfacing with the human brain.

Moderated by Kristen Maitland from the California-based Chan Zuckerberg Initiative, the panel session also featured representatives from key US funding bodies the National Science Foundation, the National Institutes for Health, and the "ARPA-H" scheme that, like ARIA, seeks to support high-risk, high-reward projects that achieve measurably better healthcare outcomes.

MIKE HATCHER

Simmons

continued from page 15

she believes to be the key operating principles behind using T centers as the backbone of scalable, fault-tolerant quantum technologies, and described what scalable quantum computer networks will look like once built. As she says: "What we're working with is so different to classical systems."

Along the way, Simmons highlighted that T centers emit at telecom wavelengths and can therefore be harnessed to network large numbers of chips and quantum systems. She also pointed out how huge numbers of high-quality I/O ports — even to the per qubit level — are instrumental to quantum computing and networking, with the critical role of connectivity to building the quantum technologies of tomorrow also being explored.

"In principle, any silicon color center could be used in our architecture, you'd just have to change its wavelength to telecom wavelengths through transduction — it might be slower but you could still do it," she says. "And you could also apply our operating principles to other hardware architectures, including neutral atoms."

Different qubit architectures aside, Simmons reckons the community needs to start thinking about post-quantum cryptography and the development of algorithms that are resistant to attack by a quantum computer. She also believes the thorny issue of quantum cost should be addressed soon.

"There's a lot of smart people out there working on all kinds of architectures that can move towards [scalable] entanglement schemes, but as a scientific group, we haven't really figured out what the resource costs are going to be," she says. "It will eventually come down to who wins on rate, quality, and cost."

Indeed, Simmons is confident that the next decade will bring huge quantum development. According to the Photonic founder, a decade ago, few were thinking about optical quantum computing, and quantum technology in general had not reached commercial settings. "Today we have this massive quantum network from IBM that has hundreds of thousands of users — it's wild how much the quantum world has changed," she says. "In another ten years, we're going to see many applications that haven't been identified today — it's going to be a very different quantum space, and boy, it's going to be good."

REBECCA POOL

Padgett

continued from page 15

watching quantum computing and related companies with interest. For example, Scotland-based M Squared, exhibiting at Photonics West, manufactures a range of quantum systems based on atom interferometry, including accelerometers and gravimeters, as well as optical lattice clocks, and has also developed 'Maxwell', a neutral atom quantum computer.

Combining M Squared's photonics and quantum systems with Rydberg atom and quantum algorithms from University of Strathclyde researchers, the platform can already support at least 100 qubits and scaling plans are in place.

"I've spent years thinking that quantum computing is over-hyped, but now I think I was wrong," says Padgett. "I'm looking at what M Squared and others have done, and am now thinking they're getting very close to doing something useful and all those venture capital companies were right after all."

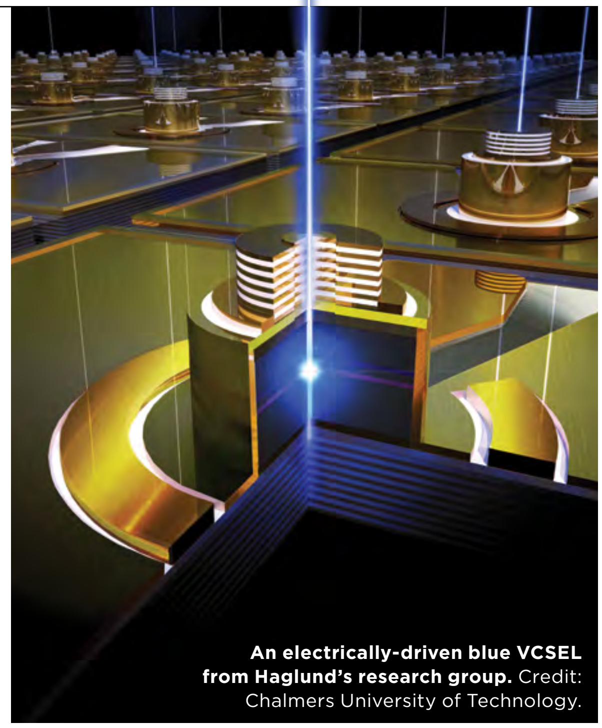
Padgett also highlights PsiQuantum, which is using networked optical technologies including low-loss waveguide modulators and highly efficient detectors, to develop a silicon photonic chip-based quantum computer. The Palo Alto start-up is aiming to build the world's 'first useful computer', and chief executive Jeremy O'Brien has said in the past that the company will build a 1 million qubit quantum computer in the coming years. Professor Geoff Pryde, senior quantum researcher at PsiQuantum, presented his invited paper, 'Integrated photonic quantum computing: towards large-scale systems', at the Photonics West Quantum Computing, Communication, and Simulation IV conference on Monday. And Senior Director of PIC Test and Measurement, Brennan Peterson is a panellist at the special event, 'Quantum West Business Summit: PICs for Quantum 2.0', held on January 30.

"Before long, we'll have [quantum computers] that can solve difficult optimizations — travelling salesman-type problems... And it seems that we're really close to the point where a quantum computer will be able to optimize solutions better than any classical machine," says Padgett. "Once upon a time people thought of quantum computing only in terms of code-breaking, but the space has become much richer now."

REBECCA POOL

Deep UV sources: Challenges to solve and opportunities to grasp

Åsa Haglund explains to the OPTO conference why pushing semiconductor lasers to shorter wavelengths is no straightforward matter.



An electrically-driven blue VCSEL from Haglund's research group. Credit: Chalmers University of Technology.

Photonics engineers, always seeking new lasers for fresh applications, have for some time been keen to manufacture semiconductor sources emitting in the deep UV or UVC range below 280 nanometers wavelength.

Excimer lasers operating in that range already exist, but those devices are based upon gas discharge and are bulky, inefficient, and expensive. Creating compact and cost-effective deep UV semiconductor laser diodes — analogous to those already available for longer wavelengths — would be a much more desirable route.

This can be easier said than done. As Åsa Haglund from Sweden's Chalmers University of Technology explained during a plenary session of the SPIE Photonics West OPTO conference, manufacturing a deep UV semiconductor laser brings developers up against a set of fundamental challenges.

"Producing UVC emission requires the introduction of aluminum into the established gallium nitride semiconductor materials, in order to increase the band gap of the material," noted Haglund. "But when you do so, the electrical resistivity increases greatly. This makes the injection of current for electrically-pumped sources more tricky."

Åsa Haglund, Professor of Photonics, Microtechnology and Nanoscience at Chalmers University of technology, located in Gothenburg, Sweden. Credit: Chalmers University of Technology.

The optical quality of the sources has also proven to be a hurdle, due to the difficulty of manufacturing the required materials with low numbers of defects. The density of defects directly affects the light emission capability of the semiconductor, while pits or pyramidal distortions on the surface are larger in relation to the wavelength and lead to increased scattering losses that degrade the device.

And in addition to those obstacles, thermal effects come into play. Early demonstrations of new diodes often have very low wall-plug efficiency with much of the input power generating unwanted heat, and UV lasers are no different. But the AlGaN material needed for UV has a thermal conductivity that is an order of magnitude lower than that of GaN used for blue lasers, making thermal issues correspondingly more severe.

'A lot of things are problematic'

"The material you need has very high resistivity and therefore generates a lot of heat that you can't extract, and emission of shorter wavelengths is even more sensitive to material irregularities than conventional emitters," summarized Haglund. "A lot of things are problematic."

But today progress is being made on all of these fronts. Reducing the number of defects in the semiconductor material is a question of optimized manufacture, a goal always being sought for semiconductors for all device types, not just lasers. Haglund anticipates that laser developers seeking higher quality materials will benefit from material advances now being made for all purposes.

Meanwhile the electrical issues might be tackled through ingenious developments in laser architecture, such as tunnel junction laser diodes or distributed polarization doping. These advances are currently active research fields in themselves, but have already brought the improvements in conductivity, which enabled the world's first demonstration of a deep UV laser diode.

And thermal problems, likely to be improved by these advances in materials and architecture, might be tackled further through judicious introduction of layers of material with more desirable heat conduction properties.

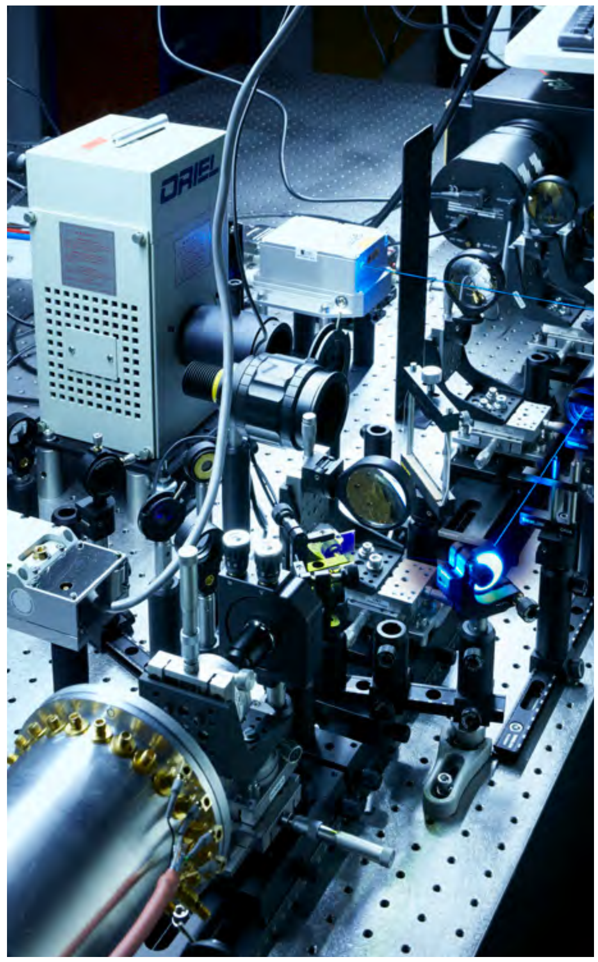
Disinfection for Covid-19 and future pandemics

As these challenges are met, deep UV semiconductor lasers could then become valuable in multiple applications. The question is, which application will be the first to adopt them?

"I can foresee low-power surface-emitting deep UV devices being readily used in 2D arrays to process UV-curable materials more cost effectively than the sources currently employed," said Haglund.

"Infrared vertical cavity surface-emitting lasers (VCSELs) are used today to heat-treat plastics and other materials, so arrays of deep UV VCSELs could become equally useful in those settings."

Disinfection and sterilization will likely be another broad market. During the Covid-19 pandemic, significant worldwide research efforts and funding were directed towards the use of UV illumination to kill the SARS-CoV-2 virus, and into how UV sources could best be used to disinfect solid surfaces, liquids, and air.



A blue laser spectroscopy set-up in Haglund's laboratory. She says that laser developers seeking higher quality materials will benefit from material advances now being made for all purposes. Credit: Chalmers University of Technology.

"Deep UV semiconductor laser diodes should be able to provide more directional and higher power irradiation than a conventional LED source for this purpose," Haglund noted. "There is also research underway into how short wavelength light, around 240 nanometers, makes such shallow penetration into the skin that it might allow treatment of antibiotic resistant bacteria without causing significant damage to the tissues."

Applications in sensing may also benefit, with tunable deep UV laser diodes for spectroscopy potentially able to detect ozone for atmospheric studies or climate monitoring.

"Pushing semiconductor laser diodes into the deep UV is a multidisciplinary project, a combined effort involving both material and device researchers," said Haglund. "Innovative solutions from both fields will be needed to get around the fundamental material limitations involved. But as we do so, I expect new applications to open up which we have not yet foreseen."

TIM HAYES

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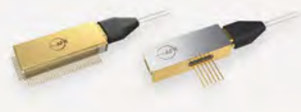

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