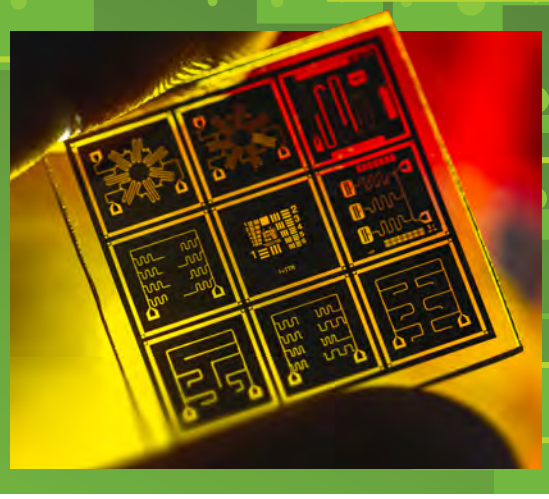
WEDNESDAY
EDITION

SPIE. | optics.org | WEDNESDAY, JANUARY 31, 2024

PHOTONICS WEST SHOW DAILY



NSF-funds quantum leap
p. 30

That's handy: Q.ANT's NV magnetometer (Booth 4205) measures tiny magnetic fields in the range of 300 picotesla at room temperature. Based on quantum physics, nitrogen vacancies (NV) in diamonds enable precise measurement of magnetic fields, even in the sub picotesla range. Michael Förtsch, CEO, said, "Our NV quantum magnetometer could enable the control of prostheses by human muscle signals, among multiple potential applications." Credit: Joey Cobbs.

Quantum West Business Summit opens positively

Accenture's Carl Dukatz identifies technology and trading opportunities and challenges.

The first Quantum West Business Summit opened Tuesday, billed as "the premier forum where industry leaders meet to discuss the opportunities, challenges, and progress towards commercializing quantum technologies." This year's program kicked off with a business intelligence report from Carl Dukatz, managing director of Accenture, a leading provider of strategy, consulting, technology, and operations services.

Dukatz told the well-attended event that quantum "continues to hold the promise of becoming a revolutionary technology across computing, communications, and sensing.

"Evidence suggests that forward-thinking businesses are going a step beyond quantum demos and experiments to quantum-inspired solutions which use knowledge gleaned exploring quantum techniques. I am going to talk about where this innovation flywheel is taking off and what it means for the ecosystem," he said.

Dukatz has led the creation of dozens of quantum applications and prototypes, published research, and business perspectives

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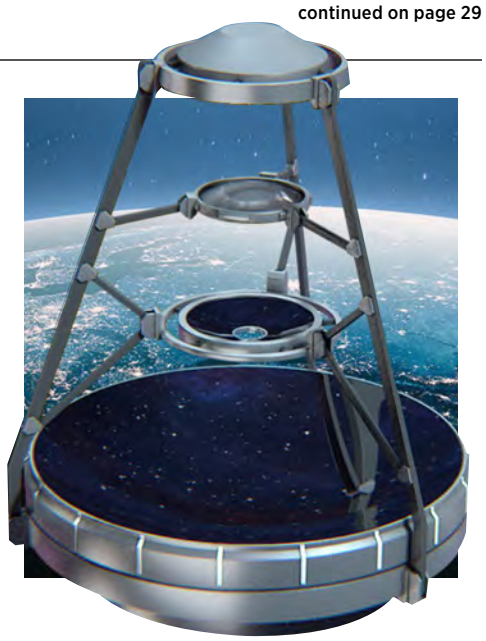
DARPA targets liquid optics

Liquid mirrors show promise as low-cost solutions for meter-scale reflecting surfaces.

Narcissus, it seems, was on to something when he gazed at his reflection in a pool of water. Today, researchers at the US Defense Advanced Research Projects Agency (DARPA) are pursuing liquid mirrors (LMs) — albeit with liquid metal rather than water — as a lower-cost alternative to glass mirrors for telescopes.

"Once you get out into the you know, eight- to 10-meter scale... there aren't many of those [mirrors] in the world," said DARPA Program Manager Michael Nayak on Monday at SPIE Photonics West. "And so how might we be able to imagine a different paradigm?" DARPA's answer is the Zenith program to develop modeling tools, materials, surface and field controls, and structures to demonstrate a meter-scale LM telescope. It is primarily a ground-based program, "but we do

continued on page 03



Liquid mirrors could be cost-effective for meter-scale apertures. Credit: DARPA.

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)

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

JOB FAIR
10 AM – 5 PM Moscone West, Level 1

LUNCH AND LEARN: PRACTICING ALLYSHIP
12 – 1 PM Moscone West, Community Lounge (Level 2)

PHOTONICS TECHNOLOGIES FOR DATACOM: COMPLEMENT OR COMPETE?
1:30 – 2:30 PM Moscone Center, Expo Stage, Hall DE (Exhibit Level)

SUCCESSFUL DEPLOYMENT AND COMMERCIALIZATION OF QUANTUM TECHNOLOGIES
3:30 – 5 PM Moscone Center, Room 155 (Upper Mezzanine South)

CHALLENGES IN FREE-FORM MICRO OPTICS: BRIDGING INNOVATION AND PRODUCTION
4 – 5 PM Moscone Center, Expo Stage, Hall DE (Exhibit Level)

OPTO POSTER SESSION
6 – 8 PM Moscone West (Level 2)

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

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SPIE Global Business Forum gives industry executives the big picture

Getting down to business (l-r): SPIE's Andrew Brown, Tematys' Thierry Robin, Michele Nichols from Launch Team, Carlson Caspers patent expert Iain McIntyre, Yole Group's Jean-Christophe Eloy, John Lincoln from Harlin, Needham & Company's Brian Perrault, SPIE's Jennifer O'Bryan, and Bo Gu from BOS Photonics. Credit: Peter Hallett.

More than 220 executives and key stakeholders from the photonics community were served up a veritable buffet of photonics-market analysis and industry insight at the inaugural SPIE Global Business Forum. An impressive lineup of international analysts and industry insiders delivered talks covering global market data and trends impacting the global photonics industry. The event was supported by key sponsors Chroma, NTFL, Optimax, Rudd Optical, and Thorlabs

In his review of the latest size of the global industry, SPIE Senior Director of Global Business Development Andrew Brown reported that despite the backdrop of chip shortages, a global pandemic, ongoing conflicts, and rising costs, the SPIE-defined "core components" market would likely rise to $379 billion in 2024 — more than double the figure of $180 billion when the SPIE team first measured it in 2012, and equivalent to a compound annual growth rate (CAGR) of more than 7 percent.

Digging deeper into the technologies and applications that are driving that growth, Thierry Robin from the French market analyst firm Tematys came up with a figure of $115 billion as the aggregate for the three main elements of any photonic system — light sources, optics, and sensors. By 2027, that total should reach $158 billion, with Robin explaining that the increased photonic content in key markets such as the automotive industry would see the components market grow faster than that for optical systems. The analyst also highlighted metamaterial optics and on-chip spectrometers as two key areas to watch, with "huge" growth anticipated over the next few years.

Adding more detail on the optoelectronics front, Jean-Christophe Eloy from the Paris-based consultant Yole Group tipped microLEDs and silicon photonics as two technologies that would drive the next growth cycle of the photonics industry, before the audience gained a Wall Street perspective with the thoughts of Needham & Company's Brian Perrault. Emphasizing the ongoing impact of higher interest rates that ended the "cheap money" era and have subdued merger and acquisitions activity, he pointed to the growing influence of private equity firms seeing photonics technologies as a way to unlock value in large end markets. "There's a lot of trapped capital that needs to be deployed," Perrault said, noting the ongoing attractiveness of the life sciences sector, thanks to its relative stability in terms of both supplier relationships and lack of price sensitivity. One thing he would not be drawn on was any firm prediction of interest rate changes this year, instead pointing out that reducing inflation and keeping it stable would help matters after two years of price shocks.

Thoughts then turned to China in the form of consultant Bo Gu's local laser market update, before SPIE's director of government affairs Jennifer O'Bryan shared her insights on a global political landscape that looks anything but stable right now.

MIKE HATCHER

Zenith

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have our eye on large space-based apertures," Nayak said, and that includes segmented mirrors.

When rotated at a constant angular velocity, fluid surfaces take the form of a paraboloid that can focus light. "This is a principle that's been around since the mid-2000s," Nayak said, "and there are some folks in this room who did some of that pioneering work."

Liquid mirrors could replace glass in future ground- and space-based observatories. Credit: DARPA.

In addition to cost, other advantages of LMs, he said, include that they are easy to fabricate, diffraction limited up to three meters, never need recoating, damage resistant/self-healing, and would be scalable to large sizes.

One big limitation, however, is that LMs cannot slew or tilt off-Zenith. "The second that they go even the smallest bit off axis to track the target…all of that nice liquid spills and I no longer have an imaging surface," Nayak said. Moreover, "as you get out to larger and larger sizes, now it's no longer the glass [that is] scaling, it's the size of the torque motor."

The Zenith program, then, is looking at alternatives to mechanical rotation to drive a tiltable, soluble surface, namely, capillary, magnetic, or electrostatic forces. Capillary actuation can be much stronger than gravity in getting the liquid spread out from its reservoir and then using magnetism to control the imaging surface. But it might also be possible to engineer the mirror structure using only magnetic forces to control the fluid spread and then pin it in place.

But now the torque motor issue has been replaced with magnets that are hot, heavy, expensive, and electromagnetic coils could disrupt the mirror surface. Electrostatic force, Nayak said, could do away with those power and control problems. "You can drive, control, and flatten liquid metals typically by using nothing but voltage," he said. "So, for [a mirror] at the meter scale, we're looking at something on the order of 500 to 600 volts. Nothing crazy."

Nayak says the Zenith program focuses only on liquid metals because they show the most promise for mirrors. The challenge, however, is that most liquid metals oxidize rapidly so that a reflecting surface would be time limited. Mercury, of course, would work as a controllable reflecting surface, but it's too toxic.

Moving forward, Nayak says DARPA is excited about work on ferrofluids at the University of Laval, in Canada, and the agency is supporting research programs on capillary driven mesoporous mirrors, magnetically driven ferrofluid mirrors, electrostatically driven segmented mirrors, and immiscible liquids and permanent magnetism at General Atomics, GE Research, Honeywell, and Lockheed Martin. Part of the deal, he says, is that software and simulation tools specific to liquid mirror performance modeling will be released to the astronomical community as an open-source repository.

WILLIAM SCHULZ

GENERATING SPARKS

SPIE and Beckman Laser Institute partnership honors laser tech and biomedical pioneer Michael W. Berns

Michael W. Berns. Credit: UCI Beckman.

Beginning in 2024, SPIE, the international society for optics and photonics, will be partnering with the Beckman Laser Institute (BLI) to honor its founder and former chairman and CEO Michael W. Berns, who passed away in 2022. SPIE and the BLI will each contribute $200,000 toward the Berns-SPIE SPARK Grants; the $400,000 total will cover multiple grants over the next two years.

The Berns-SPIE SPARK Grants will provide support to young research scientists – either postdocs or faculty – who are using lasers and other optically based systems to study basic cell process or to develop technologies to diagnose and/or treat diseases in an innovative way that could have a major impact on the field of biophotonics.

Berns, the 2022 winner of the SPIE Gold Medal, the Society's highest honor, was a professor of surgery and cell biology at the University of California, Irvine (UCI), as well as a founder of the first Laser Microbeam Program, the Beckman Laser Institute, the UCI Center for Biomedical Engineering, and the UCI Photonics Incubator. A pioneer in the use of laser technology for medical and biological research, Berns applied his research across a variety of illnesses including skin disorders, vascular and eye diseases, and cancer.

To apply or learn more visit spie.org/spark

DANEET STEFFENS

AR headset-makers focus on polymer waveguides

Zeiss smartglasses spin-off tooz has set up a partnership with China's North Ocean Photonics, as revealed by tooz CEO Kai Ströder in his opening plenary talk on Tuesday at SPIE AR|VR|MR.

The deal sees tooz augment its existing curved waveguide capability, which the company has developed for prescription applications in particular, with planar waveguides manufactured at scale by North Ocean. tooz describes the partnership as a "leap forward in the market readiness of prescription technology for waveguides."

Stressing the importance of providing consumers needing an eyewear prescription with a simple solution for smartglasses, Ströder said:

"Augmented-reality glasses without prescription can only serve small niche markets — regardless of which combiner, waveguide or technology is providing the virtual image. That is why tooz develops prescription solutions for both its own proprietary optical platform and for various other competitive optical systems."

North Ocean and tooz say that they joined forces last year to deliver diffractive planar waveguides with seamlessly integrated, individual vision correction.

"Through a combination of push and pull lenses attached to the planar waveguide, the smartglasses wearer can then see both the AR content and the environment sharp as well as the augmentation in the desired distance," they announced.

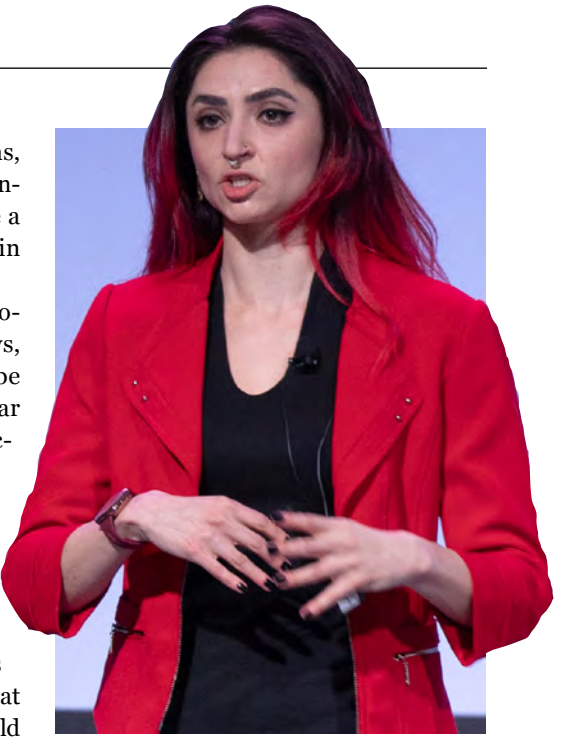
Ströder told the Moscone West audience that although the company's approach yielded a relatively narrow field of view, that was a trade-off worth pursuing to better meet the needs of prescription correction particularly for consumers in Asia where correction is especially prevalent among younger people who are the more likely early adopters of AR technology.

Tao Lin, the chair of Shanghai-based North Ocean Photonics, added: "Through this partnership with tooz on customizable vision-corrected solutions, we added another dimension of functionality to our waveguides, which will be a crucial step to enable mass adoption in the future."

Said to be compatible with both monochrome and color micro-LED displays, the Chinese firm's waveguides can be used in both monocular and binocular devices, are currently in mass production, and said to be easily scalable.

Following Ströder, Julie Frish from Magic Leap revealed that the Silicon Valley AR headset maker was working to develop polymer waveguides for potential use in future products. A senior engineer in Magic Leap's waveguide materials unit, Frish said that although polymers offered a smaller field of view compared with the glass waveguides deployed in the company's commercial headsets until now, the trade-offs with lower weight, durability, and speed of manufacture were worth pursuing.

"The process is fast!" she said. "It takes minutes, rather than hours or days, to make polymer waveguides." So far, the Magic Leap team has produced a monochrome waveguide weighing just over a gram — less than a third of a glass equivalent — with Frish saying that they are also working on a full-color version offering a 30-degree field of view. "[It's a] compelling pathway to achieve widespread adoption," she concluded, adding that Magic Leap was interested in establishing new partnerships to work on the technology.



Julie Frish of Magic Leap. Credit: Joey Cobbs.

MIKE HATCHER

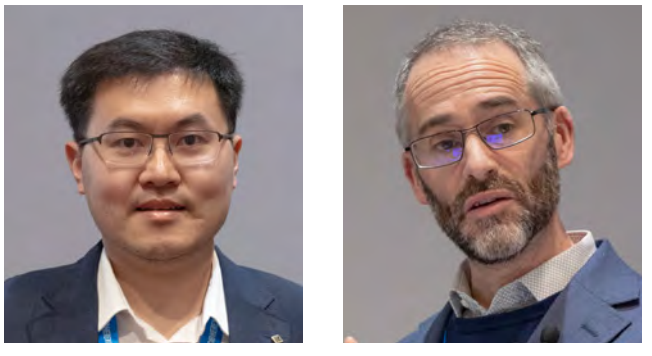
Translational Research Forum rewards two biophotonics innovators

Sunday's BiOS Translational Research Forum saw two pioneering biophotonics innovators recognized for their achievements in using light in different ways to treat chronic wounds and to restore sight in patients suffering from age-related macular degeneration (AMD).

The annual awards are judged by a panel of senior photomedicine experts from leading hospitals and research centers worldwide. Criteria for deeming a novel technique worthy include solving an unmet medical need, improving the standard of patient care, and innovation in the solution.

This year's Translational Research chairs, who introduced the event and named the winners, are Gabriela Apiou, PhD, and Aaron Aguirre, MD, PhD, who both work at the Wellman Center for Photomedicine and Massachusetts General Hospital Research Institute and Harvard Medical School. They recognized two 2024 Translational Research Award Winners working in different fields of photo-biomedicine. Then both winners gave a summary of their work.

The first, Research Fellow Jie Hui, of Massachusetts General Hospital, and Harvard Medical School has been recognized for his development of the use of antimicrobial blue light for wound infection control, including "identifying a new therapeutic window, treatment regimen, and a wearable device to deliver the treatment." The second is Professor Daniel Palanker, of Stanford University, for his work in photovoltaic restoration of sight in age-related macular degeneration.



Recognized for their achievements: Jie Hui of Massachusetts General Hospital, and, representing Daniel Palanker, Keith Mathieson of the University of Strathclyde. Credit: Joey Cobbs.

Hui explained, "Our optical solution to treating bacterial infection in chronic wounds is based on delivering blue light between 400-430nm onto the wound to reduce infection. The key benefits of our approach are that it's drug-free, there is a broad spectrum anti-microbial effect, and there is no bacterial resistance."

He explained the mechanism of the blue light destroying a range of long-chain bacteria, and how wearables or implants delivering blue light at a constant low dose offered significant advantages over high-dose irradiance treatments, which can damage tissue. His group had also identified an effective lower power density regime (of 1-10mW/cm^2) than the typical conventional range of 50-200mW/cm^2.

Hui concluded by identifying the market potential for the technique — primary patients with chronic wounds as well as in veterinary applications — and summarized its practical benefits thus: "Antimicrobial blue light means reduced wound debridement, reduced dressing changes, accelerated healing, and lower costs."

Palanker was not available in person, so his award was received, and presentation delivered by collaborator Keith Mathieson of the University of Strathclyde, Glasgow. Mathieson described the structure of the eye, explaining that a typical healthy retina has around 120 million photoreceptors, comprising 6 percent cones and 94 percent rods.

"However, geographic atrophy (GA) caused by AMD leads to the loss of receptors," he said. "GA affects three percent of people over 75 and 25 percent of those over 90. On top of that, 42 percent of GA patients are legally blind."

Mathieson then described the Palanker solution: a light-sensing subretinal implant designed to function with an adapted pair of spectacles worn by the patient featuring a projector integrated in the "temple" (side piece) and reflector on one lens. The wearer also has a mini-control panel to adjust brightness, contrast, edge sharpness and dynamic range.

Mathieson explained that the Palanker group had spent much time assessing optimal sensor pixel size in the subretinal photodiode to maximize the effectiveness of restoring the user's sight. The group has been commercializing its technology under the PRIMA brand and working with the company Pixium Vision.

Pixium Vision is currently conducting in France and the US, two feasibility clinical trials with PRIMA, for patients with severe vision loss due to retinal degeneration caused by the dry atrophic form of AMD.

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Nuclear options emerge after tough year for industrial lasers

Support for both fusion and fission applications offer a glimpse of future laser deployments that may one day transform the energy industry.

2023 turned out to be something of a tough year for industrial laser vendors targeting more conventional applications. Although widespread fears of a global recession proved overly pessimistic, reduced smart phone production coincided with sharply rising interest rates in Western economies and deepening geopolitical tensions.

In October, IPG's CEO Eugene Scherbakov said that the fiber laser firm was facing a challenging capital investment cycle, with weak industrial demand in Europe compounded by fears of overcapacity following years of heavy investment in the previously buoyant Chinese market for electric vehicle (EV) batteries.

The UK's Science and Technology Facilities Council's "Vulcan 20-20" laser upgrade, a six-year effort, should result in a better understanding of laser fusion when completed. Credit: STFC.

EV battery production had become a major market for IPG over the past couple of years and accounted for around 20 percent of its total sales in 2022, up from 10 percent in 2021. On the plus side, those worries about overcapacity in China — where the EV battery sector is significantly more mature than in the West — appear to be temporary, with Scherbakov anticipating a recovery in 2024, and demand likely to build further in the US.

Recent figures from Bo Gu at consulting firm BOS Photonics suggest that, despite a weak post-pandemic recovery, the Chinese market for lasers still grew by around 6.5 percent in 2023 — admittedly a slower rate than is typical, and mostly to the benefit of the domestic suppliers who now dominate the region. For 2024, Gu has forecast a return to double-digit growth, amid growing opportunities for blue and ultrafast sources.

Coherent has also hinted at a 2024 recovery, indicating that while its industrial business had been hit by macroeconomic weakness in 2023, some major investments in both OLED and micro-LED display manufacturing capacity should lead to an eventual rebound.

"The move to larger OLED formats and new OLED display types will require new excimer laser annealing systems along with new lasers for cutting," reported the firm in a letter to shareholders in November, adding: "We have also started receiving sizable purchase orders in connection with new [OLED] fab investments in China." OLED adoption in larger formats should see that segment of the displays market grow from $3 billion in 2023 to around $8 billion in 2026, with Coherent expecting to find further success with its new "Python" diode-pumped solid-state lasers for annealing applications.

But what also emerged in 2023 was the prospect of an entirely new sector, one that until a year ago still seemed to be over the horizon. *If* — and it remains an extremely big "*if*" — laser-based fusion becomes a viable commercial enterprise in the future, developments over the past 12 months or so will likely go down in history as critical milestones.

Prior to December 2022, inertial confinement fusion with energy gain, or ignition, remained only a theoretical possibility. Then came the experimental breakthrough at Lawrence Livermore National Laboratory (LLNL) — although without replication even that remarkable achievement would have counted for relatively little. But by December 2023 the LLNL team had repeated the feat at least three more times (and in fact probably five more times, suggests a recent *Nature* article), on each occasion gaining more understanding about the ways subtle variations in laser and target conditions influence energy output.

December 2023 saw more announcements. Not experimental breakthroughs this time, but what look like key steps nonetheless. A few days after the White House used the COP28 climate summit to outline its vision of an international framework for fusion energy partnerships, the US Department of Energy revealed $42 million in funding for three laser fusion development "hubs", to be hosted by LLNL, Colorado State University, and the University of Rochester.

"Private investments in fusion companies around the world have totaled $6 billion to-date," pointed out the White House announcement. "The rise in private fusion investments and growing interest in fusion commercialization reinforce the need for global engagement to resolve research challenges and develop international supply chains and workforces."

To be clear, the vast majority of that $6 billion has gone towards more conventional fusion technologies relying on magnetic confinement, but last year also saw some significant funding of laser fusion startups, some of which are directly involved with the DOE-backed hubs.

Examples include US-Germany outfit Focused Energy,

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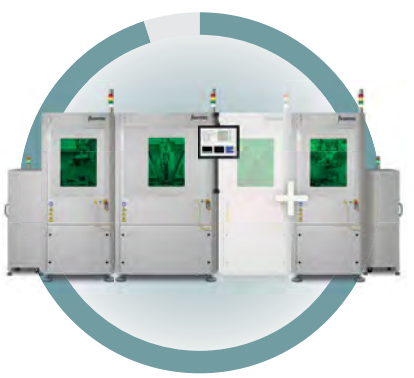

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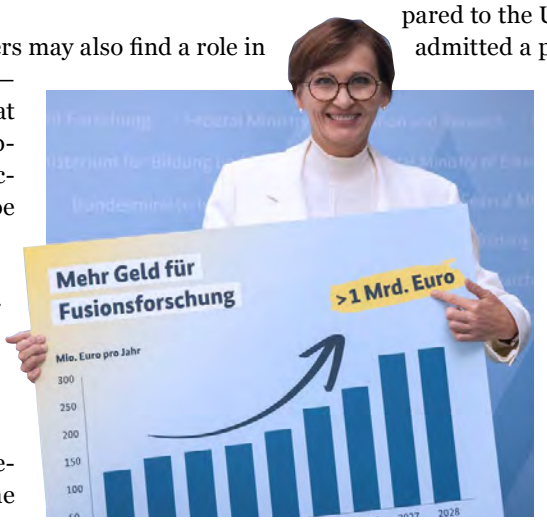
Nuclear options

continued from page 07

Japan's EX-Fusion, Munich-based Marvel Fusion, and Blue Laser Fusion — the latter a Palo Alto firm co-founded by Nobel laureate and blue LED pioneer Shuji Nakamura. Xcimer Energy, in nearby Redwood City, is working on a KrF excimer source capable of producing more than 10 megajoules, and is involved in all three of the recently funded DOE hubs.

Interestingly, excimer lasers may also find a role in magnetic confinement fusion — Coherent said in October that the high-energy systems it typically sells into display production applications could also be used to make superconducting tape that feature in spherical tokamaks, enabling more compact magnetic confinement.



Bettina Stark-Watzinger, Germany's Federal Minister of Education and Research, announces a ramp in funding for fusion technologies in the country. While Germany has not been particularly active in fusion development, its optics and photonics industry could be critical for laser-based approaches to the challenge. Credit: BMBF.

International collaboration

As the White House announcement noted, the scale of the challenge is sufficiently enormous to require widespread international involvement. "International cooperation is critical for fusion energy to reach its potential as an abundant source of sustainable clean energy, potentially lifting more than a billion people out of energy poverty," it said.

"International engagements promote and facilitate effective public-private partnerships around the world. In addition, timely commercial fusion deployment will benefit from early international coordination on regulatory frameworks and policy implementation to facilitate fusion's market entry. As we continue to engage in scientific R&D and progress toward demonstration and commercialization, we are entering a new era in which open scientific research is crucial alongside strong intellectual property protections and enforcement."

In terms of international activity, both Trumpf and the Fraunhofer Institute for Laser Technology (ILT) are involved in the LLNL-hosted "STARFIRE" hub, hinting at the critical role that could be played by Germany's optics and photonics industry — even though the country has not exactly been at the forefront of fusion research.

"Germany has not yet established itself as a significant contributor to the field of inertial confinement fusion (ICF) or inertial fusion energy (IFE) when compared to the US, UK, Japan, Italy, or France," admitted a position paper published in September 2023 by Germany's Federal Ministry of Education and Research (BMBF).

"While China and Russia have yet to declare IFE ambitions, they have already embarked on building large-scale ICF lasers that resemble the National Ignition Facility (NIF). Nevertheless, the challenges posed by this technology are vast, and Germany has a unique opportunity to utilize its capabilities to make a significant impact and establish itself as a crucial partner in this area."

Coinciding with the announcement of its own billion-euro investment in fusion through 2028, the BMBF paper outlined several challenges that still need to be addressed for laser-driven IFE to work, including a better understanding of burning plasmas, developing efficient laser drivers and suitable targets, and creating materials that can withstand fusion conditions.

"To promote the growth of crucial and high-return-on-investment technologies for Germany, it is recommended to organize the development of enabling technologies, competencies, and capabilities in hubs," it suggests. "The fusion energy research portfolio must include technology and engineering research for a fusion power plant, not just basic plasma science."

Open innovation principles should also be encouraged to facilitate rapid progress in fusion research and commercialization, added the report, while Germany's world-leading expertise in laser technology ought to offer a key advantage in developing IFE.

"By focusing on developing capable driver concepts for an IFE demonstrator and improving laser driver and multi-gigashot laser capabilities, Germany can leverage its position as a leader in the laser industry to lay a solid foundation for competitive production of advanced high-power lasers for IFE," it stated.

ILT director Constantin Haefner added that the LLNL-led STARFIRE hub will expedite the development of high-gain target

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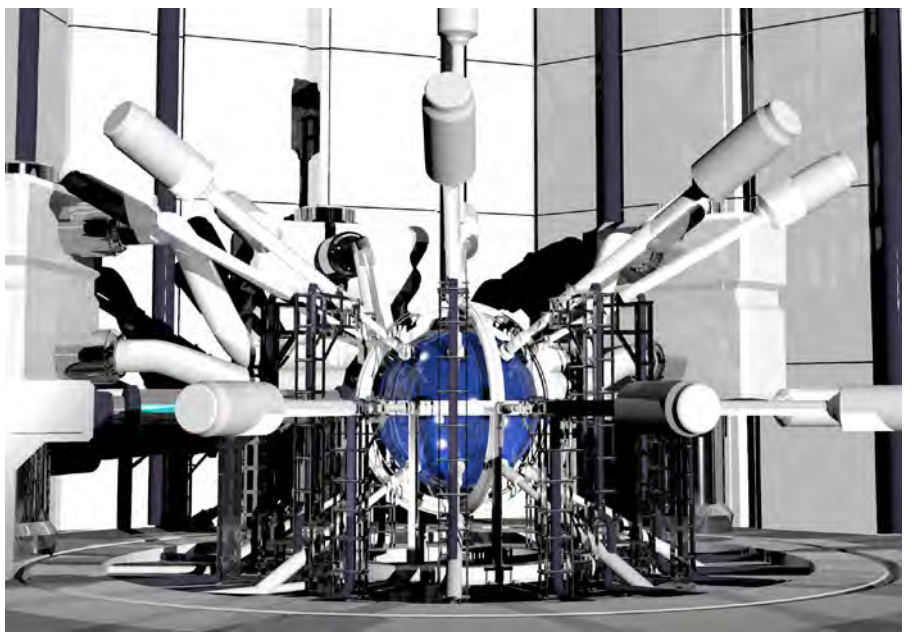
EX-Fusion's conceptual design for a commercial laser fusion reactor. Last year the Japanese startup raised $13 million in seed funding, one of several new companies in the sector to gain support. Image: EX-Fusion.



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NKT Photonics

Nuclear options continued from page 09

designs and diode-pumped solid-state laser technologies.

"Germany, with its rich history in research and development of lasers, optics, production engineering, power plant technology, and more, is excellently positioned to develop key technologies for the realization of practical fusion power plants," he said. "By fostering collaboration in transnational teams, we can accelerate progress and overcome challenges together, bringing us closer to the realization of fusion energy for a sustainable future."

Nuclear options

The UK looks like another willing international partner, following the November announcement of a "major partnership" with the US straddling the various fusion technologies. "International collaboration is key for advancing fusion and achieving our ambition of getting a commercial fusion reactor grid-ready by 2040," said Andrew Bowie, the UK's minister responsible for nuclear energy. "The UK and the US are world-leaders in this technology, and pooling our resources will unlock new private sector investment. This bold new partnership will help turn our fusion ambitions into reality."

In October, 2023, Japanese startup EX-Fusion established a collaboration with the Tokyo Institute of Technology. They aim to come up with a concept for liquid fuel blankets suitable for optical systems in future laser fusion reactors. Credit: EX-Fusion.

While the UK has typically focused its fusion efforts on tokamaks, the Central Laser Facility's "Vulcan" laser is in the midst of an £85 million upgrade to what will be known as "Vulcan 20-20" — the numbers referring to targeted increase in pulse power to 20 petawatts, alongside eight additional high-intensity beams producing a pulse energy of up to 20 kJ.

"The Vulcan 20-20 laser will help us better understand various scientific areas, from astrophysical phenomena like supernovae and solar flares to the potential of laser fusion as a clean energy source," stated UK Research and Innovation (UKRI) when it formally announced the upgrade in September.

Momentum should be aided this year when the International Atomic Energy Authority (IAEA) holds its inaugural "World Fusion Energy Group" meeting. Announcing the new event last October, IAEA's director general Rafael Mariano Grossi said that the idea is to bring scientists together with engineers, policy makers, financiers, regulators, and civil society.

"This next leg of the fusion energy journey will get us from experiment to demonstration to commercial fusion energy production," he predicted.

"Fusion is not to be confined to the laboratories and experimental centers. They, of course, are indispensable. But the ambition is to bring fusion energy to the economy. To make it part of the energy mix of the not-to-distant future, credible pathways must be identified, encouraged, and supported."

IAEA Director General Rafael Mariano Grossi addresses the 29th International Fusion Energy Conference, held in London last October. IAEA plans to host its inaugural "World Fusion Energy Group" meeting later this year. Credit: IAEA.

Grossi also announced the launch of the IAEA's "World Fusion Outlook", intended as a global reference for authoritative information and updates on fusion energy, developments, and prospects. The first edition of that publication only lists a single laser fusion project — Longview Fusion Energy Systems' planned pilot plant — as an example of the privately funded enterprises now looking to deliver fusion energy on a commercial basis. Set up by former NIF director Ed Moses, Longview is another participant in the LLNL-led STARFIRE hub, while in 2023 it also signed a memorandum of understanding with Texas-based engineering giant Fluor.

Any eventual fusion market for high-energy lasers obviously lies very much in the future, but it may not turn out to be the only nuclear option available. Laser separation of uranium isotopes to provide the enrichment needed for nuclear fuel is hardly a new idea. In fact it was first touted decades ago. But 2023 may also turn out to have been a pivotal year for this technology, after Australia's Silex raised $81 million and said that thanks to the acceleration of a venture with US-based Cameco and Global Laser Enrichment (GLE) it was on course to complete a "commercial-scale pilot demonstration project" by the middle of 2024.

Speaking at the Shaw and Partners Uranium Conference in November, Silex CEO Michael Goldsworthy said: "The acceleration preserves the option of commencing commercial operations at the planned Paducah Laser Enrichment Facility as early as 2028."

The effort positions GLE to become a reliable and versatile supplier of three key nuclear fuel products: natural uranium; low-enriched uranium for the existing nuclear reactor fleet; and high-assay material for next-generation advanced reactors, including small modular reactors. Other laser isotopic separation applications look possible as well — Silex has highlighted its ability to produce enriched "zero spin" silicon for quantum computing applications, as well as a lutetium radioisotope that could find use in cancer therapy.

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SPIE Catalyst Award finalists showcase EDI, outreach, sustainability programs

The successful finalists are implementing satellite technology, engaging education techniques, and skills-enhancing training to improve the communities they serve.

This year, in addition to the regular slate of industry-focused SPIE Prism Awards — in areas ranging from healthcare and sensing to lasers and quantum — SPIE is introducing the SPIE Catalyst Award. This new recognition honors for-profit companies and their specific social or environmentally focused programs, programs that offer significant positive impact, either within the workplace, on society at large, or on the environment. Finalists for the inaugural Catalyst Award in 2024 are Ball Aerospace, Intel Corporation, and Thorlabs for consideration in one (or, in Intel's case, two) of three categories: Equity, Diversity, Inclusion, and Accessibility; Community engagement, Outreach, Education, and Training; and Environmental Sustainability.

Intel

To address expected semiconductor engineering and manufacturing worker shortages — per McKinsey & Company, official estimates project a shortage of some 300,000 engineers and 90,000 technicians in the US by 2030 — and to meet Intel's 2030RISE goal of increasing the organization's representation of women in technical positions to 40 percent, Intel has developed two innovative and inclusive semiconductor workforce development programs, QuickStart and Returnships. Together, they aim to remove barriers to entry and re-entry into industry, while creating a larger, more diverse and inclusive workforce. Both the QuickStart semiconductor-technician training program and the career return-ship "Relaunch" programs offer diversity-aware access to potential high-growth careers, incorporating new pipelines for training and engaging key talent.

Quick Start students practicing wearing "bunny suits" worn by manufacturing technicians at Intel, alongside Portland Community College mascot Poppie the Panther. Credit: Intel

The QuickStart program partners with local community colleges near Intel's Oregon and Arizona factories to prepare students for entry-level technician positions. The ten-day courses emphasize small class sizes and hands-on training; having completed these courses, students are prepared to interview for entry-level manufacturing technician positions at Intel or other advanced-manufacturing companies. The program also works with local workforce and community groups to recruit and train people historically underrepresented in the technology industry, including women, people of color, veterans, people with disabilities, and people from low-income and rural communities.

Addressing the anticipated engineering shortage, the relaunch program targets experienced hires who have had a career break — perhaps through caregiving or military service — and re-integrates them over an approximate 16-week period, removing potential barriers to a smooth return to employment. This program, too, provides training and experiences to members of the community who may otherwise be overlooked by traditional hiring practices. The majority of returners are offered a full-time position at Intel at the the end of their 16-week reintegration; even if they are not offered a position, the express goal is that this enhanced training experience could ultimately help them obtain work at another company. As part of Intel's application statement makes clear, increasing the quantity, quality, and diversity of those who can see themselves in advanced manufacturing is imperative to address the expected industry shortfalls.

"Being named a finalist for the SPIE Catalyst Award is both an honor and a testament to Intel's unwavering commitment to building a more inclusive advanced manufacturing ecosystem by increasing awareness and accessibility to advanced manufacturing as a high wage, fulfilling career," noted Intel Business Operations Manager, Technology Development, Diane Vidmantas. "This acknowledgment reflects Intel's dedication to collaborate within our community to inspire more women and underrepresented minorities to pursue and succeed in technology careers which ultimately contributes to a world where diversity is a driving force for innovation and progress."

Thorlabs

Launched in 2023, the Thorlabs Mobile Lab Experience brings a fully functional photonics lab to high schools, colleges, and universities all over the US with the goal of educating students and communities on the importance of the photonics industry and fundamentals of light. The peripatetic

continued on page 15

Catalyst Awards continued from page 13

lab will highlight advanced topics in photonics by curating a variety of interactive experiences, hoping to generate excitement and curiosity in learners of all generations.

The program aims to democratize photonics outreach and education, while also building curriculum that engages new learners as well as appealing to those working in more advanced photonics research settings. While visiting dozens of schools and universities, the program will also focus on locations and communities where access to photonics learning may be limited. With its travels underway, the lab has already fostered connections with hundreds of aspiring photonics technicians and scientists, generating increased interest in optics technology and engineering programs. As they interact with more communities on their travels, the lab managers will continue to develop experiential-rich content and hands-on lab work to educate students on the importance of photonics in daily lives, inspiring the next generation of photonics professionals.

The Thorlabs mobile lab program takes a multifaceted approach:

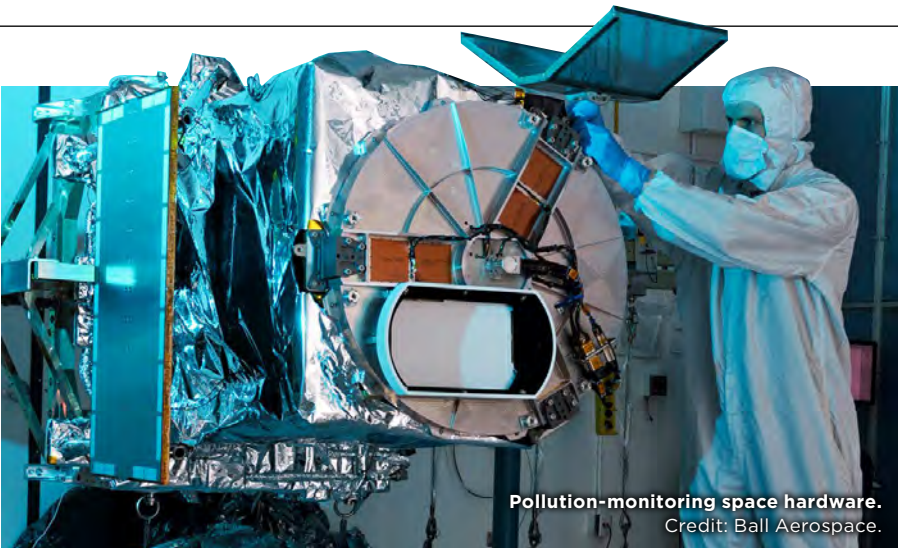
- Encouraging curiosity through an interactive introduction to photonics, including the areas of spectroscopy, biomedical optics, optical communications, and optical fiber technologies, drawing the connection between everyday phenomena and photonics concepts and encouraging an early appreciation of the subject.
- Hands-on courses are designed to facilitate a seamless transition from theory to practice, cultivating a skilled workforce equipped with the expertise required to handle sophisticated photonics setups for both academia and industry.
- Building foundational knowledge and a strong conceptual framework — ideally leading to further innovations — by exploring the basics of photonics systems such as fiber processing and optical coherence tomography.

The Thorlabs Mobile Lab Experience. Tour the lab on the exhibit floor this week at Photonics West. Credit: Thorlabs

"The Thorlabs Mobile Lab Experience is the realization of a long-standing idea conceived by our founder and CEO Alex Cable," notes Thorlabs Vice President of Sales and Business Development Michael Mohammadi. "The mobile lab represents just the beginning of our efforts; we are curating a series of Thorlabs Experiences aimed at fostering learning, education, career paths, and the development of the photonics community. We recognize the significant role that Thorlabs plays in our industry and see these experiences as our way of helping to build awareness for our industry and helping to better prepare the photonics workforce of the future. The enthusiasm and engagement of the students who have participated in the lab experience have confirmed that our mobile lab offers a unique learning experience for students across our industry, and our nomination for SPIE Catalyst Award further validates the substantial time and resources we›ve invested in this project from a photonics-industry perspective."

Ball Aerospace

According to the World Health Organization, outdoor air pollution causes 4.2 million premature deaths a year, making reliable, regular, and frequent pollution measurements key to global health and well-being. With their Geostationary Environmental Monitoring Spectrometer (GEMS) and Tropospheric Emissions: Monitoring of Pollution (TEMPO) technologies, Ball Aerospace has created two geostationary ultraviolet/visible spectrometers that provide regional, hourly, high-spatial resolution measurements of atmospheric elements critical to understanding air pollution — of the air we breathe, these instruments offer an opportunity to take informed action that will improve people's health and well-being: by giving governments, businesses, and individuals the data they need to make informed decisions about air quality, stakeholders and communities can work together to create a healthier, more sustainable world for future generations.



Pollution-monitoring space hardware. Credit: Ball Aerospace.

GEMS and TEMPO are electro-optical sensors consisting of a hyperspectral, UV/Vis imaging spectrometer, telescope, and precision pointing devices that make high-quality measurements of Earth's radiance that can be transformed into environmental measurements. TEMPO launched on April 7, 2023, from Cape Canaveral Space Force Station as part of NASA's Earth Venture Instrument program. On August 24, 2023, the TEMPO instrument released its first images spanning greater North America. Now that the instrument is active, the TEMPO team is busy validating its spatial, spectral, and radiometric performance, as well as the science data processing chain. Once this process is complete, members of the public and the scientific community will have access to near real-time information, packaged by the Center for Astrophysics, a collaboration between the Harvard College Observatory and the Smithsonian Astrophysical Observatory, and distributed by NASA. GEMS, which provides similar data from across Southeast Asia, was launched in 2020 as part of an air-quality monitoring mission for the South Korean National Institute of Environmental Research.

A few examples of the potential impact of this satellite technology:

- With access to hourly air pollution data around the globe, scientists can identify problem areas, empowering local groups to implement effective solutions and build resilience that reduces harmful emissions and improves air quality.
- According to the American Lung Association, more than 4 in 10 Americans live in places with unhealthy levels of air pollution. In the past, the world's ability to mitigate poor air quality and the damage it causes was hampered by a lack of actionable information. The data GEMS and TEMPO provide will close this gap. The data will also help with epidemiological studies related to air quality.
- According to Harvard's School of Public Health, poor air quality inordinately impacts low-income communities due to a lack of emissions regulations and disproportionate placement of pollution sources nearby low-income neighborhoods. GEMS and TEMPO will help scientists identify regions that are most heavily impacted by poor air pollution, influencing regulatory changes to create healthier air for all.
- Atmospheric emissions of pollutants end up in our streams, lakes, and other natural bodies of water. The ability to better track and quantify emissions will assist in understanding pollutant loads into our hydrologic systems.

"Our team is thrilled to be included among the finalists for this new Catalyst Award, and to be recognized alongside such a remarkable group of innovators in the field," said Alberto Conti, vice president and general manager, Civil Space, Ball Aerospace. "We're confident this nomination will focus even more attention on the vital work we, our customers, and our partners are doing with GEMS and TEMPO to further highlight the importance of these groundbreaking pollution monitoring tools."

From providing a path toward improving global health to scaling up the process of building a reliable and robust optics and photonics workforce, all three of these SPIE Catalyst Award finalists are shining an exciting light on a variety of possibilities by putting them into tangible and impactful action. The winner of the SPIE Catalyst Award will be announced during the SPIE Prism Awards on Wednesday, January 31.

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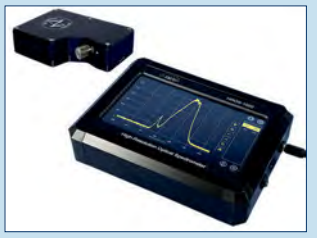

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Photonics innovation for sustainable development

At Photonics West 2024, attendees will discover the breadth and depth of research applying optics and photonics to humanity's biggest challenge — improving life today without harming future generations.

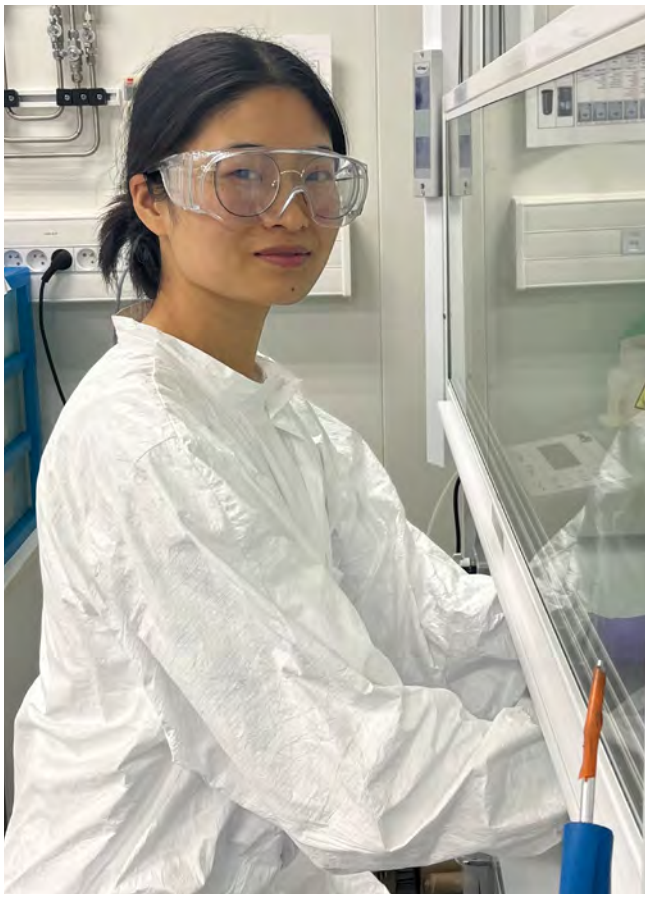
Shubhra Pasayat from University of Wisconsin-Madison. Credit: UWM.

Photonics is an academic field and industry with a unique and central responsibility to shape sustainable development. Already today, Earth observing satellites track climate change and enable sustainable farming, energy-efficient lighting and fiber-optic communication reduce our collective energy consumption, efficient and cheap solar panels allow us to generate and store green energy, and endless examples of photonics technologies are delivering resource-saving industrial processes. But more can be done.

With many commentators on the COP28 climate talks in December saying that pledges made by countries to take action on climate change do not go far enough, eyes are on science and technology to provide novel solutions that can help keep global warming below 1.5 °C above pre-industrial levels and help society reach net zero emissions by 2050.

This is why there is a wealth of content at this year's conference highlighting 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. These include Plenary presentations, such as 'Silicon photonics: the quest for sustainable growth' with Roel Baets on Monday; an entire track dedicated to 'Photonic Technologies in Plant and Agricultural Science'; the SPIE Sustainability Best Paper Award that recognizes outstanding papers from BiOS, LASE, and OPTO; and numerous presentations dotted throughout the conference showcasing innovative ground-breaking research contributing to sustainability efforts.

For instance, on Monday, Huiru Ren (Institut des Nanotechnologies de Lyon, France) presented 'Titanium dioxide nanoimprint for sustainable photonic sensor application' at the OPTO conference. The technologies Ren and colleagues are developing fall into the same category as point-of-care (POC) diagnostics systems, like blood glucose monitors, pregnancy tests, and Covid-19 test kits. These single-use devices are increasingly finding favor for their low cost, accessibility, and hygiene, but are also beginning to have a negative impact on the environment in terms of waste.



Huiru Ren from the Nanotechnology Institute of Lyon, France. Credit: INL.

Ren and colleagues aim to change this picture by developing and fabricating photonic crystal biosensors made from titanium dioxide, a non-toxic, abundant, inexpensive, and stable material. These photonic chips are well-suited to multiple parallel sensing, which is a route towards reducing the volume of disposable products and waste by testing for multiple conditions/indications at the same time, while providing more reliable diagnostics. Moreover, they are fabricated via nanoimprint lithography (NIL). NIL is high-throughput, cost-effective, and compatible with titanium dioxide. When commercialized, the biosensors promise cost-effective, low environmental impact, mass biomolecular screening for a range of diagnostics, as Ren summarizes: "This work supports the UN goals of sustainable development on all key aspects: economic, ecological, technological (material, manufacturing and device life cycle), as well as societal (application to POC sensors for better healthcare)."

Another OPTO presentation that might pique your interest was given by Shubhra Pasayat (University of Wisconsin-Madison). In her talk on Tuesday, titled 'Long wavelength emitters using porous III-nitrides', Pasayat described her efforts to make micro-LEDs more efficient. Already, LEDs require 75 percent less energy and last up to 25 times longer than traditional incandescent light sources. However, shrinking their size for near-eye and other applications results in large reductions in LED efficiency, particularly for red emitters.

Maxime Romanet from FEMTO-ST, CNRS, France. Credit: CNRS.

Pasayat has made a breakthrough in establishing the same efficiency benefits as macro-sized LEDs at the microscale, developing a method of producing indium gallium nitride (InGaN) with a layer of flexible porous GaN that can expand with higher concentrations of indium in red-emitting devices, while maintaining high overall efficiency. "The unique aspects and benefits of the approach are to push the fundamental material properties beyond conventionally known limits by introducing some new materials," she says. "These have the promise of extending the efficiencies of current devices by at least 5x over state-of-the-art LEDs, resulting in high energy efficiency as well as lower greenhouse emissions." Her efforts recently culminated in the world's smallest red-emitting nitride device (6 microns dimension) with 1 percent efficiency. She is now intensely working on improving this technology to increase efficiency to 5 percent or higher, when it can have a pathbreaking impact on the miniaturized LED landscape.

Elsewhere, on Tuesday, Maxime Romanet (FEMTO-ST, CNRS, France) presented his OPTO paper '140 km Brillouin optical time domain reflectometry based on single-photon detector'. Alongside colleagues Kien Phan Huy and Jean-Charles Beugnot, and collaborator Etienne Rochat (Omnisens, Switzerland), Romanet has developed a cutting-edge fiber distributed temperature sensing (DTS) technique for undersea electrical cables. Such cables transport energy produced by offshore wind farms over very long distances. Monitoring their temperature continuously, all along their length, is critical in ensuring cable integrity and condition, and in receiving early warning of incipient faults. However, current DTS systems based on the measurement of Brillouin backscattering are limited in range (75 km) or require expensive underwater amplification modules.

The new technique Romanet and collaborators have developed is based on photon counting rather than direct optical detection. "The main advantage of our solution is to be able to measure a temperature signal up to 140 km thanks to a low noise level, without the need for

access to both sides of the fiber — this performance is 40 percent longer than current laboratory techniques, and 75 percent longer than commercial devices," says Romanet. "This implies that two devices like ours, on each side of a fiber, allow us to measure the temperature along a 280 km installation without requiring any optical signal repeaters along the optical fiber, nor a Raman amplification system, nor coding solutions, unlike other techniques."

Photonics is an academic field and industry with a unique and central responsibility to shape sustainable development.

Like OPTO, LASE also harbors hidden gems at the bleeding edge of sustainable photonics research, both from academia and industry. On Monday, Alexander Garifal (Photonics Industries International) presented 'High pulse energy UV laser for next generation thermal processing and SiC semiconductor annealing applications'. Electric vehicles are key to decarbonizing transport, and efficient and functional semiconductor annealing is becoming critical in electric vehicle manufacture, where silicon carbide (SiC) is replacing silicon in, for example, traction/drivetrain inverters, on-board chargers, and DC/DC converters. The talk focused on Photonics Industries' DM Series Nd:YLF UV Nanosecond Lasers, a category of diode-pumped, solid-state lasers producing stable and high pulse energies ideal for annealing wide-bandgap compound semiconductors like SiC.

Another fascinating LASE presentation with potential high impact in sustainability was presented by Graham Kaufman (University of Nebraska-Lincoln) on Wednesday. Titled 'Functionalization of copper for enhanced electrocatalytic reduction of carbon dioxide via ultrashort pulse laser surface processing', the talk is relevant to carbon capture and utilization.

Electrochemical reduction of carbon dioxide on copper can produce useful compounds such as methane and ethanol, but the technique has not yet passed pilot-scale production capacity. Doctoral candidate Kaufman and colleagues have developed a method of enhancing the process. By applying ultrashort pulsed laser surface processing, they managed to produce micro- and nano-scale features on copper substrates. The resulting laser-functionalized copper surfaces were then post-processed to enhance stability and product selectivity. The hope is that this technique could be used to tune copper's catalytic activity and selectivity, to finally deliver on the promise of converting carbon dioxide to valuable fuels and chemicals.

These talks are just a small snapshot of the exciting academic and industrial work being carried out by speakers and attendees at this year's conference that will form the sustainable technologies of the future. To discover more and plan your event schedule, filter Photonics West presentations by the Sustainability application track in the online conference program.

BEN SKUSE

Confining light and molecules opens new vistas for research

Minnesota's Professor Sang-Hyun Oh says roadblocks to fabricating high-quality small photonic structures are gone, promising a wide array of new applications.

Prof. Sang-Hyun Oh from the Department of Electrical and Computer Engineering at University of Minnesota. Credit: University of Minnesota.

At first glance, Sang-Hyun Oh's work developing methods for building nanophotonic structures appears niche. His team has pioneered several advanced techniques to make high quality nanostructures that are very small and very flat, including template stripping and atomic layer lithography. The former involves engineering an inverse pattern in a reusable silicon template, depositing a metal film on the template, and then removing the patterned metal. The latter utilizes atomic layer deposition (a technique widely employed since the 1970s) to create a patterned film, and then removing excess metal with simple adhesive tape.

On their own, these nanofabrication techniques represent an improvement on state-of-the-art nanophotonic structure engineering. But it is what they and other advanced nanofabrication methods enable in terms of being able to confine and manipulate light and molecules that gets Oh excited. "We are working on neurodegenerative diseases, a bit of a quantum optics, quantum light — matter interaction, a lot of data analysis, and we also use machine learning," he says. "So starting from photonics, I get to experience all these cool topics."

In his Nano/Biophotonics Plenary titled 'Engineering photonic nanostructures for next-generation sensing and imaging' on January 30th, Oh showed attendees that the roadblocks to fabricating high-quality small photonic structures in university labs are gone, and hopes to inspire them to explore the wide array of applications this enables.

For example, his nanofabrication methods have allowed his team to make slits that are as small as two nanometers in width. When light is confined in such small gaps, interesting things happen. "We can boost the field intensity quite dramatically, we can observe some nonlinear impacts, we can use that field to trap molecules," Oh says.

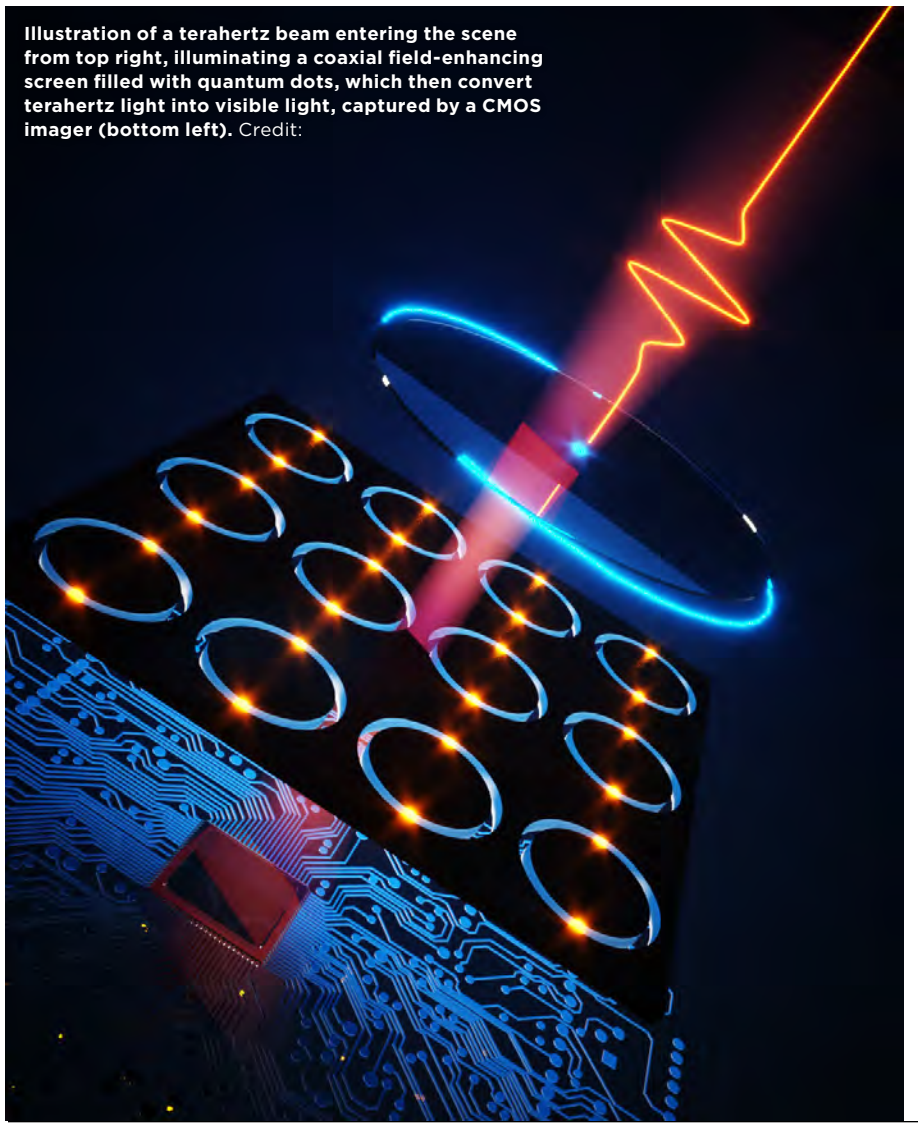


Illustration of a terahertz beam entering the scene from top right, illuminating a coaxial field-enhancing screen filled with quantum dots, which then convert terahertz light into visible light, captured by a CMOS imager (bottom left). Credit:

Just one of these interesting phenomena Oh has explored with collaborators is the coupling between light and molecules. As light interacts with molecules in smaller and smaller cavities, it reaches what is known as the strong coupling regime, where the mode inside becomes partly light, partly matter, featuring interesting hybrid aspects.

When this happens, it is thought that light and matter intertwine, giving rise to new quasiparticles known as polaritons. Polaritons may potentially modify the molecular vibrations and electronic attributes of materials, which could have numerous impacts on the design of devices such as LEDs and lasers. "At the moment, this is still fundamental research," warns Oh. "But now that we can make resonant optical cavities that have a width as small as just a few nanometers, we have a unique platform to study strong coupling between light and molecules."

In another study, Oh has been collaborating with researchers from MIT and Samsung for a number of years to develop a new kind of camera that can rapidly detect terahertz pulses, which lie between microwaves and infrared light in the electromagnetic spectrum. Traditional detectors for terahertz waves operate at cryogenic temperatures to pick out extremely low energy photons from background noise. Incumbent devices generally require an array of terahertz detectors, each producing one pixel of the image, making them expensive (tens of thousands of dollars), slow, and bulky.

Affordable terahertz detector

The new device operates at room temperature and pressure, is fast and small, and if commercialized would cost a fraction of the price of existing terahertz detectors. Affordable terahertz detectors could have numerous applications, allowing border officials to reliably expose weapons, environmental scientists to monitor different environments without damaging them, and quality control officers to check for errant food, cosmetics, and other products.

"A few years ago, our collaborators found that if you apply a very strong field using semiconductor quantum dots as media, you are able to convert very low energy terahertz light into visible light," Oh explains. Quantum dots are nanometer-sized semiconductor particles with advantageous optoelectronic properties. In early work, the researchers discovered that a low energy terahertz pulse strips an electron off one quantum dot and transfers it to another, before recombining with the original. Crucially, this process is typically accompanied by the emission of high energy visible light. Converting low energy light into high energy photons is known as upconversion.

"Utilizing this upconversion phenomenon, we can use a standard CMOS visible camera to image terahertz pulses," says Oh. The camera is formed from patterned conducting layers with sub-micron insulating gaps in which an incident terahertz field is strongly enhanced, and quantum dots deposited on these field-enhancement structures. An incident terahertz field then induces electroluminescence, producing visible light that is detected with a conventional CMOS element.

"I think that's one of the most exciting optoelectronic applications I'm working on," Oh reveals. "The next big step forward that we are still working on is, can we apply this idea to infrared radiation or blackbody radiation, can we image them using a standard CMOS camera and turn it into a thermal imaging tool? We theoretically think it is possible but there are many technological barriers."

Though Oh is extremely enthusiastic about these research directions, what is firing his imagination most is applying photonics to biosensing. Oh trained in microelectronics and optoelectronics, but has harbored a passion for biotechnology for a long time. This passion was first kindled during his postdoc period, in which he studied microfluidics and molecular biology. "It was then that I realized that there's a lot of opportunity to merge photonics technologies with life sciences," he says. "When I started my independent faculty position at the University of Minnesota, I decided I will use these technologies from photonics and electronics to make new tools for life sciences."

One such tool Oh and his team developed was an ultrasensitive biosensor capable

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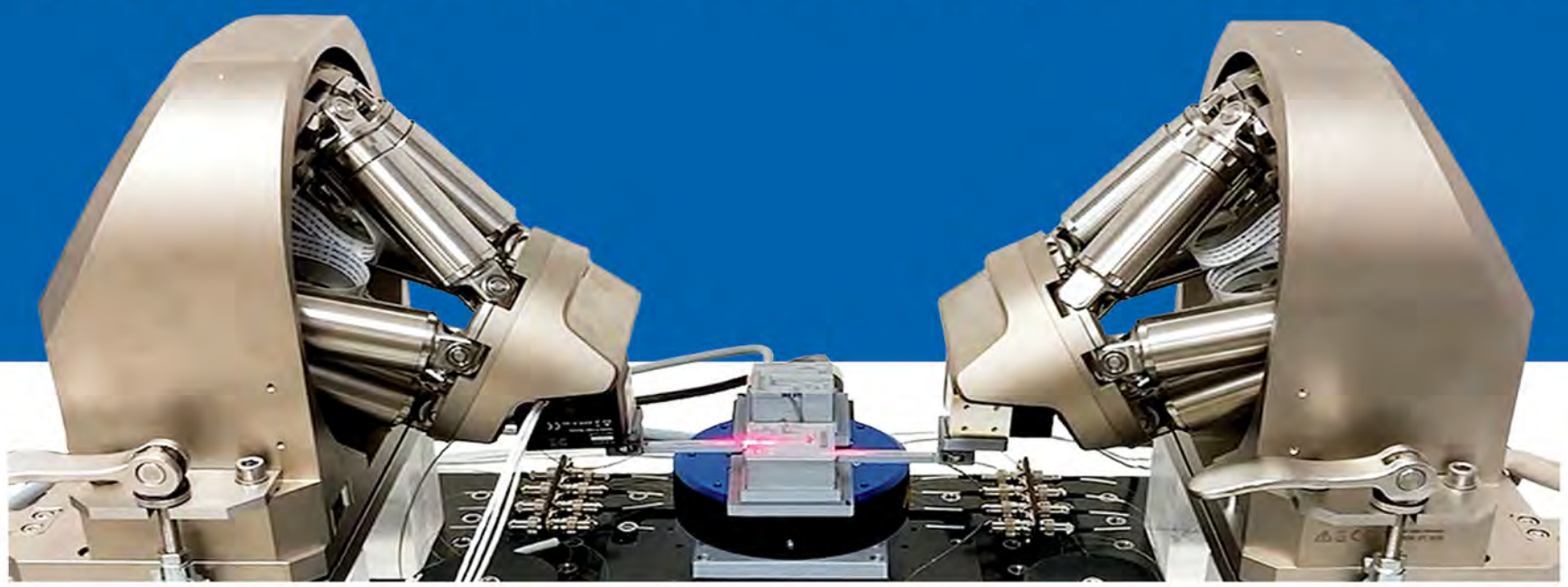

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Creating a clearer vision of the future

The Neurotechnologies Plenary Session highlighted advances in neurophotonics technologies, from light-based *in-vivo* brain imaging to mapping human brain function.

Opening the Neurotechnologies session, Tomáš Čižmár, professor of wave optics at the Friedrich-Schiller University, head of the Fibre Research and Technology department of the Leibniz-Institute of Photonic Technology, and the head of Complex Photonics laboratory at the Institute of Scientific Instruments, introduced a 110 µm thin laser-scanning endo-microscope, which enables volumetric imaging of the entire depth of a mouse brain *in vivo*.

"Multimode fibers are pretty amazing!" says Čižmár. "When you shoot laser light into them, these cool speckles pop up, they're not random and boring; they're beautiful and super powerful. It's like uncovering a secret code! If you can figure out how to work with this complex light, you can do things that seem impossible, like peeping into the deep corners of the brain to see how it wires itself."

At the Leibniz-Institute of Photonic Technology, Čižmár and his colleagues strive to understand light transport in optical fibers and the true role of disorder, which could enable imaging in motile animals. "We try to stay abreast of the latest developments in wavefront shaping and fiber optics, contributing to enhancements in imaging speed, field of view, contrast, and other vital imaging parameters," says Čižmár. "Also, we place significant emphasis on translating our work into practical applications. While we conduct *in vivo* imaging in our lab, we extend our reach through numerous missions to prominent European neuroscience institutes. During these missions, we apply our technology to address specific challenges, ensuring that our research finds tangible applications in the real world."

As for the future of light-based biomedical imaging, the domain has grown immensely, and its diverse branches will be shaped by new application challenges as well as technological opportunities. "In my specific field, a significant leap forward is anticipated when phase modulators boasting megapixel resolution and a refresh rate exceeding 10kHz become accessible at a reasonable cost," says Čižmár. "This is poised to funnel many methods of modern microscopy down the optical fiber into deep brain structures."

Anna Wang Roe, director of the Interdisciplinary Institute of Neuroscience and Technology at Zhejiang University, discussed infrared neural stimulation (INS), an optical stimulation methodology which delivers brief trains of small heat pulses leading to neuronal response modulation.

"In the past several years, we have tailored this method for stimulation of focal activation of single cortical columns in ultrahigh field MRI in the monkey brain, revealing functional networks of mesoscale sites at brain-wide scale," says Roe. "The network activations, which span sensory, motor, cognitive, and limbic areas of the brain, offer novel understanding of network architecture in the primate brain. These findings have important implications for precision medicine, brain-machine interface design, and the organization of primate intelligence."

Much of current neuroscience research focuses on neuronal function and their circuitry, bringing critical understanding to behavior and disease. However, much less attention has been devoted to understanding the architecture of the brain, i.e. where the neurons live and how the lines of communication are organized. "I aim to study the 'columnar connectome'

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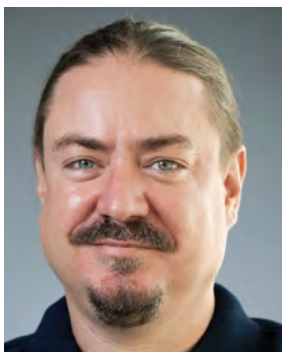

Tomáš Čižmár, Friedrich-Schiller University/Institute of Scientific Instruments.

Adam Eggebrecht, Washington University and the Brain Light Laboratory.

Neurotechnologies continued from page 23

to understand organization of brain-wide networks," says Roe. "I hope that someday we will have a basis for understanding primate intelligence. Understanding the organization of brain circuits at mesoscale will be a valuable guide for achieving precision and personalized medicine, for information theory and artificial intelligence, and for pushing technologies for interfacing with the brain."

Roe hopes that her audience sees that science and technology go hand in hand, as equals. "This work resulted from science questions that called for technological advances, that then generated new questions that then demanded additional technology, and so forth. Each stands on the other's shoulders to provide a clearer vision of the future."

"Mapping human brain function has revolutionized systems neuroscience," says Adam Eggebrecht, associate professor of Radiology at Washington University in Saint Louis and head of the Brain Light Laboratory. "Common brain mapping methods such as fMRI offer promising sensitivity yet pose significant methodological challenges in studies of naturally behaving children due to the loud, constraining environment and extreme susceptibility to motion-induced artifacts. Recent developments in high-density diffuse optical tomography (HD-DOT) have demonstrated dramatically improved image quality over traditional fNIRS methods." In his presentation "Towards illuminating brain function throughout childhood development with high-density diffuse optical tomography," Eggebrecht discussed challenges associated with mapping brain function in children in natural settings, recent advancements in developing HD-DOT methods, and applications in childhood development, autism spectrum disorder, and critical care environments. "Brains are fascinating and challenging to investigate, especially in intact and behaving humans."

At Washington University, Eggebrecht contributes to team-taught classes on biomedical imaging principles and applications. He also helps arrange for visitors to present their work at seminars. These presentations are opportunities to foster conversations across disciplines, addressing challenges in biomedical-imaging science that may impact everything from basic research to clinical care. At Brain Light Laboratory, Eggebrecht mentors students and other trainees across a variety of disciplines, fields, and backgrounds as they explore creative solutions to problems in physics, engineering, and neuroscience.

Through his presentation, Eggebrecht showed how optical imaging of deep tissue can provide reliable information about human brain health during natural behavior and at point-of-care. "We are still in the early days of what will become possible," says Eggebrecht.

Gal Mishne, Halıcıoğlu Data Science Institute, UC San Diego.

Adam Charles, Johns Hopkins University.

In the final talk, Adam Charles, assistant professor at the Department of Biomedical Engineering at Johns Hopkins University, and Gal Mishne, assistant professor at the Halıcıoğlu Data Science Institute at UC San Diego, co-presented "Data science for imaging: the Micro, the Meso, and the Macro," a look at recent advances in the analysis of functional optical microscopy to maximize its utility across scales.

"The question of scale is paramount to the next era of systems neuroscience," says Charles. "We focus on questioning algorithmic designs that were developed in the age of single-to-few neuron recordings, and considering how we might adapt — or start from scratch — to meet the needs of the data we will be collecting in the next 20 years of neural imaging."

A main focus in Mishne's research group is nonlinear methods that reveal the geometry and topology of large-scale high-dimensional data. "Such techniques, however, can introduce artifacts and distortions," says Mishne. "We're addressing this challenge by both developing measures to identify and quantify this issue, as well as to learn representations with low distortion. Applying such techniques to neuroscience recordings can reveal dominant patterns of neuronal activity and connectivity over multiple spatiotemporal scales and learn behavioral motifs in an unsupervised and unbiased way."

KAREN THOMAS

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Expanding Toptica is living the 'all wavelengths' dream

With new lasers and frequencies for 2024, the Munich-based laser developer is targeting three markets – quantum, biophotonics, and test & measurement.

Toptica has introduced new wavelengths at 445 nm and 447 nm with its TopMode single-frequency diode laser series, pushing the boundaries of high-resolution Raman spectroscopy, microlithography, multi-wavelength digital holography and interferometry. Credit: Toptica.

Headquartered near Munich Germany, but with offices worldwide, Toptica Photonics develops and manufactures high-end laser systems for scientific and industrial applications. The company's range includes diode lasers, ultrafast fiber lasers, terahertz systems, frequency combs, and continuous-wave fiber lasers and amplifiers. Toptica's website boasts: "OEM customers, scientists, and over a dozen Nobel laureates have acknowledged the world-class exceptional specifications of our lasers, as well as their reliability and longevity."

Political engagement: Toptica's Dr. Thomas Renner (left) and CEO Dr. Wilhelm Kaenders (right) in conversation with visitor Dieter Janecek, who is economic policy spokesman of Germany's B'90/Green parliamentary group, during a 2022 visit to the firm's Graefelfing headquarters. Photo: Toptica.

With 490 employees, the company continues to grow and expand its range. For example, earlier this month (January, 2024), the firm's French subsidiary Toptica Photonics SAS (formed following the acquisition of Azurlight Systems, in 2023) has taken over product sales in France. This move is intended to strengthen the collaboration between the company and its France-based scientific and industrial customers. Toptica Photonics SAS will also distribute the products of partner company HighFinesse GmbH, which offers wavelength meters and other optical analyzers.

The company's President and CSO is Dr. Thomas Renner, who has a background in ultrafast laser development and applications in physical chemistry; he gained his PhD at the University of Munich, not far from the company's headquarters in Gräfelfing. Dr. Renner previously worked at Baasel Lasertech, where he was group leader for pulsed YAG lasers in R&D. He joined Toptica in 2005.

Show Daily interviewed him about recent developments at the company, its latest offerings on show at this year's Photonics West, and his thoughts on the outlook for the market.

Show Daily: What are the notable recent developments at Toptica?

Thomas Renner: 2023 again was a year of growth and profitability for the company, which has now reached more than €130 million in annual turnover with nearly 500 employees. Early last year we made the successful acquisition of French laser manufacturer Azurlight Systems, which now operates under the brand of Toptica Photonics France. All of our three core markets — quantum technology, biophotonics, and test & measurement — show strong health and growth for us.

Having grown our space to 18,000 square meters in the Gräfelfing, Munich facility alone, we have also taken the opportunity to invest into a larger social meeting zone for our employees, who are now returning from home office working and very much enjoy connecting with their colleagues in person again. We call this the "fireplace" effect. In our case this includes a pool table, Foosball table soccer and table tennis, a highly popular puzzle table, a stage for on-site events like quiz nights or science slams. In fact, there is also a real small fireplace. And for our external guests, who visit us very frequently, we are just opening a new demo and customer experience area.

SD: Describe the main new products and developments on show at Photonics West

TR: In line with our longstanding company slogan "All Wavelengths", we are presenting no fewer than eight new products spanning blue to deep infrared ranges. These include new coherent lasers at 445, 468, and 488 nm, fiber coupled femtosecond lasers and new cost-effective lasers in the IR and mid-IR region. But also part of the new offerings will be locking electronics for more precise and integrated quantum lasers.

SD: In Toptica's view, what is the state of the market and likely developments and technology trends?

TR: Photonics has reached what I call the next stage of maturity. Most photons are in place, by which I mean that suitable laser power, beam quality, and so on, can be purchased from multiple vendors at most required wavelengths. However it is becoming more and more important that the end user can use these photons as a practical tool and not just as a physical experiment.

Quantum opportunities

TR: Next-generation quantum technology, such as for building quantum computers, will not be suitable with a design based on a breadboard loaded with multiple lasers and beam-shaping optics. It is essential to integrate the entire laser elements – including all peripheral locking electronics, beam switching, etc. – into one rack-based sub-system then able to fiber-deliver the photons to the quantum processing units. Toptica's Laser Rack Systems (T-rack) are bringing significant benefits to these applications, although the delivered photons themselves did not improve from a technical perspective by this integration step.

The same principle applies to fiber-coupled multi-laser light boxes, such as our iChrome MLE series for confocal microscopy. These are so deeply integrated that the end customer almost does not realize that they are operating a laser-driven microscope. And in few years you can also expect that femtosecond lasers for multiphoton microscopy will be deeply integrated into the microscope. Then the well-known picture of a fully loaded large optical table beside the microscope will fade away. For a classical laser physicist this might be a little bit sad — but for the future of photonics this is an essential step.

SD: For some years know, Toptica has been supplying specialized quantum developments; what is your view on quantum market opportunities and the future potential of your solutions?

TR: We definitely see a trend from high-end quantum applications towards out-of-the-lab applications, which still are technically high-end enough to achieve. This market is strong – both from a technical roadmap deep into the 2030s, and considering the required financial funding. We have aligned our product roadmap in coordination with the major key players and will continue to be one of the major laser suppliers to this industry.

SD: What is the likely impact on business of changing economic conditions, geopolitics through 2024?

TR: The latest changes in geopolitical developments definitely did not help to improve international technical exchange. It is now becoming more difficult to import critical optical sub-components and to export laser products. Photonics has always been a very international community, where challenges of high technical complexity were solved by different local experts from all continents. We are afraid that in future sub-eco-systems will be formed or need to be formed, which will build their own photonics supply chains. This will neither help the speed of innovation nor the required price reductions.

SD: How about the importance of

Toptica at Photonics West 2023. Credit: Toptica.

research and academic inputs into Toptica?

TR: Almost every new technical idea has started initially on academic grounds. It is very important to have strong contacts to academic innovators and be partners from an early stage. Information flow never is a one-way-street. Toptica always is happy to also provide its own ideas and technical experience.

SD: How does the company provide encouragement for students, potential new employees, and deliver training to staff?

TR: We have hired almost 100 new employees globally during the past year. The range spans experienced managers to first-job students and PhDs, through to young starters fresh from school, including apprentices for office jobs or laser manufacturing opportunities. Each of them receives detailed on-the-job training including a personal coach for the first half year. We have also increased the number of trainees to support non-academic educational paths into the laser-making industry.

SD: What is the company's involvement with industry associations, such as SPIE?

TR: We highly appreciate all photonics associations, since we believe they are the backbone for our industry. We are also happy to help where needed, such as by hosting in-house seminars or other events.

In particular, Photonics West is one of the two major laser and photonics shows in the world. Innovation here is always up to date; attendance is great and lead generation has always been positive.

MATTHEW PEACH

Confining light

continued from page 20

of probing protein structures. The biosensor combined graphene with nano-sized metal ribbons of gold. To be able to detect small amounts of molecules for disease diagnosis, light absorption and conversion to local electric fields are essential. But up to then, graphene was problematic for biosensing because it did not interact efficiently with light shining through it. Previous work had only demonstrated light absorption rates of less than 10 percent.

Using Oh's nanofabrication methods, the team managed to increase light absorption efficiency to 94 percent. When they inserted protein molecules between the graphene and metal ribbons, the technique allowed them to view protein molecules. "We spent a lot of time making ultra-smooth metallic structures that can couple with graphene," Oh recalls. "With those structures, we could observe graphene plasmons and use them to detect a thin layer of protein molecules."

In more recent studies, Oh and collaborators have been developing a diagnostic technique for neurodegenerative diseases, such as Alzheimer's and Parkinson's. In such diseases, normal proteins misfold and aggregate in the central nervous system. Current detection methods used for diagnosis such as enzyme-linked immunosorbent assay and immunohistochemistry are time-consuming and limited in terms of antibody specificity.

Instead, Oh and colleagues are pursuing a method that combines nanoparticle technology, surface chemistry, and fluorescence detection. Dubbed Nano-QuIC (Nanoparticle-enhanced Quaking-Induced Conversion), the researchers' new method significantly improves on the performance of the gold standard NIH Rocky Mountain Laboratories' Real-Time Quaking-Induced Conversion (RT-QuIC) assay. The RT-QuIC method involves shaking a mixture of normal proteins with a small amount of misfolded protein, triggering a chain reaction that causes the proteins to multiply to the point that they can be detected. Using tissue samples from deer suspected of having chronic wasting disease (an animal disease caused by misfolded prion proteins, similar to Alzheimer's and Parkinson's in humans that are related to other proteins misfolding), Oh and colleagues demonstrated that adding 50-nanometer silica nanoparticles to RT-QuIC experiments dramatically reduces detection times from about 14 hours to only four hours and increases sensitivity by a factor of 10.

"The ultimate goal is that we want to develop early diagnostics for these neurodegenerative diseases, but it's still a developing technology," Oh explains. "Doing this in a less invasive sample like blood, there is still a way to go, but we have shown that the addition of nanoparticles can speed up these reactions, so we are quite excited about some early findings."

"My work reaches nanotechnology synthesis and fabrication, and applications involving biomolecules and biological cells," says Oh. "So in my talk, I want to present some new directions and emphasize the multidisciplinary nature of this type of work, because now we know how to manipulate light and combine it at small scale, there are so many new research directions and applications to explore."

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Thorlabs sees ‘co-opetition’ as core component of industry’s success

With a booth at each of the BiOS, Quantum West, and Photonics West exhibitions and the presence of its Mobile Photonics Lab, it’s clear that Thorlabs [Booth 627] is making the most of the week in San Francisco to showcase their leadership in the industry. Thorlabs president Jenn Cable talked with *Show Daily* about industry trends, the company’s strong belief in social responsibility, and what she dubs the industry’s successful “co-opetition” — the cooperation of competitors to strengthen the optics and photonics industry as a whole.

Show Daily: What recent innovations or new products is Thorlabs bringing to Photonics West?

Jenn Cable: Thorlabs is already very well known for providing the “building blocks of Photonics” with our thousands of component parts; so this year we are highlighting our application specific tools and solutions that our customers may be less aware of. We’re excited to showcase a new photonic integrated circuit (PIC) inspection solution, built out of Thorlabs designed and manufactured components and instruments, in addition to other OEM solutions, including custom optics manufacturing and assembly.

SD: What do you see as the emerging trends or major challenges facing the photonics industry, and how is Thorlabs approaching them?

Cable: As photonics technologies mature, we will see increasing price pressures from industrial customers, but as a diversified enabling industry to other industries, we are well-placed as an industry to weather ups and downs in more volatile end markets such as semiconductors, electric vehicles, and automotive sensing.

I also want to mention the volatility and uncertainty posed by the climate crisis — as a global and geographically diverse industry with complex supply chains, it’s important that we understand the risks this crisis poses, and take action to do our part to blunt its largest impacts.

With the passing of the CHIPS Act and the Inflation Reduction Act in the US, we are seeing more and more calls to fund workforce development there. While this is in some ways a positive for the photonics industry’s own workforce development needs, we may also be competing for new workers with larger, more well-known industries. Globally, many nations are facing aging populations and will soon, if they haven’t already, be confronting similar workforce challenges for skilled and trained technicians. This is why we have created the Mobile Photonics Lab and why the work of AmeriCOM in the precision optics space and the support of SPIE for workforce development initiatives are so vital.

Thorlabs president Jenn Cable. Credit: Joey Cobbs.

SD: How does Thorlabs stay at the forefront of technological advancements in the industry?

Cable: It’s because of our role enabling our customers’ research that we are able to stay at the forefront of technological advancements in our own product development; our customers generously share their time with us, welcoming our teams into their labs, explaining their research. We listen to our customers and thereby learn how we can provide tools and solutions to get them across their finish lines faster. We also use strategic partnerships, academic collaborations, and acquisitions to venture into new and exciting areas of new product development. The first part of my career was spent outside of the photonics industry, and I’m actually surprised by the level of co-opetition within our industry. I really do believe that a stronger photonics industry benefits us all, it makes us more attractive to new graduates, especially supporting efforts to diversify our workforce.

SD: Thorlabs has a very open and positive approach to corporate social responsibility. Can you talk a little about these efforts?

Cable: On a personal note, I feel like I have an immense privilege in being a family business leader. I am able to bring my values, and the values I was raised with by my father, to my leadership every single day. Our commitment to DEI, environmental sustainability, and education outreach as a company mirrors our personal commitment.

From a business perspective, I believe, and the research bears this out, that creating a diverse and inclusive workplace has a marked positive impact on your ability to innovate and thrive as a company. If we do not make it a priority, our companies and our industry will lose out on great talent.

The harmful impact of environmental degradation and the climate crisis impact us all on both a personal level and a business one; we all have to live on this planet! Increasing volatility brought on by climate change will impact geopolitics, our supply chains, and our businesses.

Educational outreach allows us to give back to the academic community that was among our earliest customers, to spark curiosity in early career scientists and engineers about optics and photonics, and to broaden knowledge and understanding of optics and photonics among the broader public, especially among K-12 students. It’s truly a win-win-win; for Thorlabs, for our industry, and for our communities and our kids.

SD: As one of the few — but multiplying — women leaders in our industry, do you have any advice to young women thinking about a career in optics?

Cable: First, please join us! Our industry needs to recruit the best possible talent to continue to grow and innovate, and increasing the representation of women in our industry is vital to making that happen. I believe our industry is a great place to grow your career, especially if you want to remain intellectually engaged at every stage of your career. Many companies within our industry are still fairly young, and you’ll have opportunities to grow your skillset and your responsibility as your company grows.

In addition, I want to stress that, all employees benefit from more progressive family leave policies, benefits that consider the whole individual, workplaces that provide challenging and engaging work but also respect other commitments to self, family, and community. While we particularly think of these efforts as becoming a great place for women to work, they make a great place for all people to work.

KEVIN PROBASCO

Quantum business

continued from page 01

on quantum, and he has developed multiple training and workforce readiness programs for quantum practitioners. Nowadays, he is focused on helping businesses map their most challenging problems to formulations that could run more efficiently on quantum computers.

He assessed the marketplace thusly: “Since photonics components can have multiple applications, the market can increase or decrease through any of these channels. For example, if ion trap technology expands then this could increase the optical photonics use in quantum computing, whereas if superconducting shows advantage it could decrease optical in favor of microwave.”

Dukatz moved on to the state of investment for this sector, noting that “the quantum ecosystem continues to grow, now involving more than 4,000 entities. The most active regions are the US, Canada, UK, France, Germany, Spain, Netherlands, Switzerland, China, India, and Japan.”

He emphasized the continuing importance of state funding: “In 2023, government investment [in quantum] increased, powering growth. However, there was a reduction in private investments.”

Quantum photonics is expected to grow faster than individual quantum technology areas at a CAGR of 33.2 percent to reach $2.8 billion by 2030, according to Accenture. Quantum photonics is a smaller market overall than compute and communications. Quantum sensing growth is more limited due to challenges reaching economies of scale.

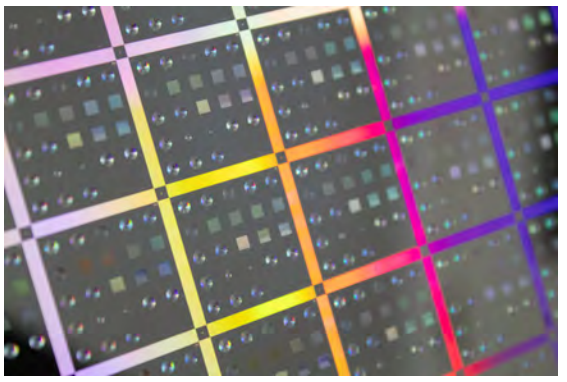
Technical challenges include maintaining performance with scaling, boosting photon source and detector efficiency, and reducing waveguide losses. On the business side, a slew of challenges remains before the sector can maximize its potential, he said. “Quantum communications and computing ecosystems are still mostly in the R&D phases. Quantum sensing struggles with economies of scale against classical alternatives, and regulation and standards are still evolving, which can complicate implementation into production.”

Nevertheless, the quantum ecosystem continues to grow and its reliance on the photonics ecosystem expanding and advancing is highly evident, Dukatz said. He concluded on a positive note: “There are opportunities for improvement of quantum photonics systems at all levels and these improvements can have ripple effects across sensing, communications, and compute — all markets for which there is incredible potential.”

MATTHEW PEACH

Moxtek readies visible-range metalenses for volume production

Photonics West exhibitor Moxtek says that its metalens products, operating in the visible and infrared spectral regions, are now ready for mass production. Speaking during Monday's AR|VR|MR conference session *Optical Architectures for Displays and Sensing in Augmented, Virtual, and Mixed Reality V*, product manager Stuart Johnson detailed the Orem, Utah, firm's development of a volume production process using nanoimprint lithography (NIL) to fabricate the novel components on 8-inch diameter wafers.



Metalenses from Moxtek. Credit: Moxtek.

The results include metalenses measuring up to 10mm in diameter and in 2x2 arrays, with a 4mm-diameter version becoming available off-the-shelf, augmenting Moxtek's existing custom offering.

"Visible meta-optics for augmented and virtual reality applications are now available thanks to Moxtek's nanoimprint lithography volume production," Johnson said, with examples available to see at the firm's exhibition booth.

Made using niobium pentoxide and aluminum, the metalenses operate from 405nm through to the mid-infrared, and are less than half the thickness of a conventional equivalent. Johnson outlined additional processes that Moxtek has been working on, including the ability to stack two components to form polarizers, waveguides, and color filters based on the nanostructured materials. Components based on other materials, including crystalline silicon, are in development.

The firm has also developed an overcoating process that both protects the metalenses and improves their transmittance across the visible spectrum by as much as 30 percent. Having processed hundreds of metalens wafers over the past couple of years, Moxtek is now offering both design and fabrication services, with the potential to produce the components at very low cost for high-volume orders. To find out more, visit Moxtek at Booth 5523.

MIKE HATCHER

FIGHTING IMPOSTOR SYNDROME TO LEVERAGE STEM INCLUSIVITY

Among professionals, including people who work in optics and photonics, some 70 percent experience so-called impostor syndrome at some point in their careers or even throughout their working lives, Joseph Williams, a professor of education at the University of North Carolina, Chapel Hill, told a "Lunch and Learn" crowd at SPIE Photonics West. It's a sobering thought as all facets of the optics and photonics enterprise seek to broaden participation in STEM fields by people of color, women, or anyone from marginalized or underrepresented groups.

Joseph Williams, University of North Carolina, Chapel Hill. Credit: William Schulz

Impostor syndrome is that sneaking suspicion that one doesn't quite belong, doesn't deserve, or will soon be exposed as unworthy in whatever career or station in life they might have achieved. It doesn't discriminate by race and gender, Williams said, although impostor syndrome impacts people of color and especially women of color, more often and with lasting negative consequences. Even highly successful people can feel its weight, he said, though their way to deal with impostor syndrome might have been through overachievement.

"When we think about imposter syndrome, one of the things I want you to take away today, is thinking about impostor syndrome in a different way. That it's not a personal problem. It doesn't stem just from poor cognition or thoughts about yourself, but from implicit and explicit biases," Williams said.

Most often, these are institutional forms of biases, Williams continued. "Our privileges, our unearned advantages, are actually directly tied to someone else's disadvantage. And that's a hard pill to swallow."

Solutions for the workplace and other institutions, he said, would include creating an inclusive working environment, addressing micro-inequities, and fostering a fair and inclusive workplace. And until the culture becomes more inclusive, he said, it is imperative to support those with impostor syndrome.

"The hardest thing to do is to think about strategies. What does that mean for me individually? What does that mean for the space that I occupy? How do I create change in that venue?"

WILLIAM SCHULZ

NSF program director outlines funding programs addressing future of photonics

Sunday's keynote presentation by Dominique Dagenais, from the US National Science Foundation, detailed recent and current programs within the NSF that specifically support advances in photonics, from fundamental research to applications. Dagenais is a Program Director in the Electronics, Photonics and Magnetic Devices, with a special interest in optoelectronics.

NSF's stated mission is "To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense; and for other purposes."

According to its website, the NSF budget for 2023 was around $9.9 billion, of which 93 percent was allocated to research, education, and related activities. In March, 2023, the NSF made a 2024 budget request of $11.3 billion. This funding is intended to support, among other projects, implementation of the CHIPS and Science Act of 2022, as well as the NSF's new Technology, Innovation, and Partnerships ("TIP") Directorate.

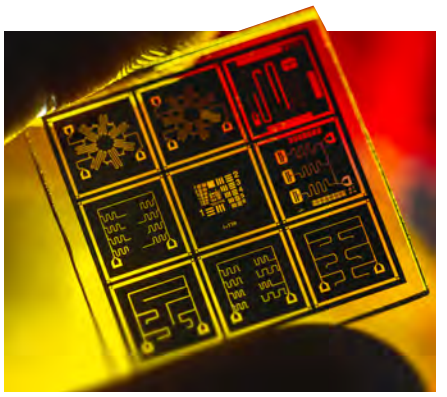
Dagenais started out by explaining the nature and purpose of NSF funding: "It is for innovative concepts in science and engineering, from fundamentals to applied research, and to topics emanating from the scientific community. In essence, it covers the supply chain between materials and devices, through integration to systems."

Considering the opportunities for photonics, Dagenais outlined certain national drivers to support potential NSF-funded projects, including: the 2018 National Quantum Initiative Act; Quantum Leap Challenge Institutes; the 2022 CHIPS and Science Act, Regional Innovation Engines, and the Future of Semiconductors (FUSE) program.

Then came the subject that many in the industry will find interesting: how are proposals selected and approved?

Some recent examples of photonics-related projects that have been funded by NSF include the following Exploratory Research (EAGER) Seed Grants: Machine learning-powered deterministic nanoassembly of ultrafast quantum photonic devices (Cornell University); and BIO EAGER: Quantum Imaging for Precise Mapping of Protein Organization during Signaling (University of New Mexico).

Besides the Seed Grants, there is a wide range of other funding models, including five-year Career Grants for Young Investigators, Core Engineering research Grants for single investigators; Incubators on Quantum Sensing, funding for Quantum Leap Challenge Institutes, and for the Physics Frontiers Center and the Center for Ultracold Atoms.



A quantum chip at the University of Maryland, an NSF Quantum Leap Challenge Institute. Credit: University of Maryland

The NSF headquarters is in Alexandria, VA; further information is available at nsf.gov

MATTHEW PEACH

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No. 399, Chuangxin 3rd Road, Tangjia, Zhuhai, China 519080
Tel: +86 756 389 8088
Fax: +86 756 389 8080
E-mail: sales@fiber-resources.com