WEDNESDAY
EDITION

SPIE. | optics.org | WEDNESDAY JANUARY 26, 2022

PHOTONICS WEST SHOW DAILY

Light control: VitreaLab wins Startup Challenge

Startup Challenge winner, VitreaLab CEO Jonas Zeuner (center) receives his winnings. Credit: Joey Cobbs

After a dynamic and focused pitch to a team of judges at the SPIE Startup Challenge, VitreaLab was announced as the winner of the annual competition.

The company is a spin-off of the Vienna Center for Quantum Science and Technology, where the co-founders both completed their PhDs in integrated optics. They are currently raising funds to help grow the company and further their technology, which has them hosting a booth on the Photonics West exhibit floor.

In a presentation titled *Laser-Lit Chip for Display Applications* Monday afternoon, VitreaLab CEO and co-founder Jonas Zeuner presented

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Lidar leader Luminar is keeping the wheels turning

After getting listed on the NASDAQ (LAZR) and signing partnerships with major automakers, the Orlando-based startup is poised for a big year

Automotive lidar pioneer Luminar Technologies, Inc. has just announced a formal partnership with Mercedes-Benz to provide its lidar technology for the German carmaker's next generation of passenger cars, enhancing both safety and autonomy.

Luminar CTO and co-founder Jason Eichenholz was walking the Photonics West exhibit when the *Show Daily* caught up with the SPIE Fellow to talk about the announcement.

"This partnership is a landmark moment that shows how Luminar lidar is progressing from our research

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Luminar's lidar under test. Credit: Luminar Technologies

DON'T MISS THESE EVENTS TODAY.

QUANTUM WEST
9 AM – 6 PM, Quantum Hub Stage, Hall A Lobby

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

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

MICROLED DISPLAY TECHNOLOGY
10:15 – 11:30 AM, Expo Stage, Hall DE

PANEL DISCUSSION ON INTEGRATED PHOTONICS
11:15 AM – 12:15 PM, Room 26 Moscone South

CHARTING A COURSE IN THE PHOTONICS INDUSTRY
2 – 3 PM, Career Hub Stage, Moscone West

FROM CONSUMER TO SPACE, 3D SENSING ADOPTION IS ACCELERATING
3 PM – 4:45 PM, Expo Stage, Hall DE

PRISM AWARDS
6 – 8:30 PM, Prism Award Stage, Moscone West, Level 2

OPTO POSTER SESSION
6 – 8 PM, Moscone West, Level 3

For the full schedule, see the SPIE Conferences app. Some events require registration.

IN THIS ISSUE.

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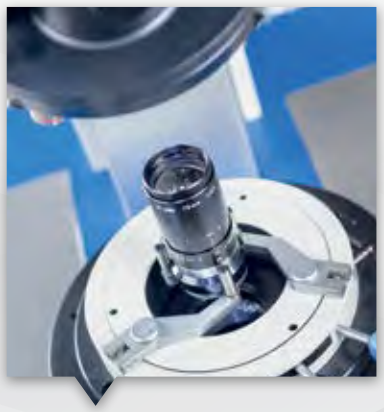

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Industrial laser market sales hit record highs – up 22 percent in 2021

Growth industry: IPG Photonics launched its LightWELD portable system last year. Credit: IPG Photonics.

The day-long Lasers & Photonics Marketplace Seminar — presented by *Laser Focus World* in conjunction with SPIE — was held Monday in the Intercontinental Hotel, adjacent to the Moscone Center. The conference, which is always sandwiched between BiOS and Photonics West exhibitions, provides an opportunity for industry executives to catch up on the state of the industry, with presentations from a range of economists, industry figures, and market analysts.

Market analysts: (l-r) Dr. Arnold Mayer and Dr. Anirban Basu.

This report focuses on the "The Global Market for Industrial Lasers and Laser Systems," presented remotely by Dr. Arnold Mayer, of Optec Consulting. However the preceding talk by Dr. Anirban Basu, Chairman & CEO of Sage Policy Group, an economic and policy consulting firm based in Baltimore, MD, had some pertinent observations.

Dr. Basu was considering the general economic global picture, comparing business, consumer, and state activities across the globe before and after the pandemic. His key conclusions, which will undoubtedly have impact on laser businesses, were as follows:

"2022 will be a year of growth, but the [global] economy will remain unbalanced with supply struggling to keep up with demand; along with rising wages amidst the Great Resignation, that will translate into higher than average, economywide inflation," he said.

"Yes, I am an economist," he added, "so I am forecasting interest rates to rise. Finally, I would say, beware of rapid declines on commodity and asset prices, at some point this year."

The industrial laser market-focused presentation by Dr. Mayer, opened with an optimistic introduction: "The industrial laser and systems markets have reached new record highs, following a total sales value increase rise of 22 percent in 2021," according to Optech's preliminary estimate.

Dr. Mayer continued, "As global economies recover, the impact of the pandemic on industrial laser markets has been decidedly mixed, depending on application and region, with the overall impact being much less devastating than first feared."

The report covered market activities of industrial laser systems split into two parts: macro (cutting, welding, drilling, marking); and micro (semiconductor manufacture, FP displays, microelectronics, solar cells), with the sales split 75 / 25 percent, respectively.

He said, "Despite Covid-19, the overall global demand for industrial lasers rose 2 percent in 2020, spurred by sales of low-cost kilowatt-class fiber lasers in China and pulsed laser for microprocessing.

"The global market for industrial laser systems reached a new record high of $21.3 billion in 2021, up 22 percent over the previous year. The market for industrial lasers also reached a new record volume of $5.2 billion in 2021."

These estimates are based on data available by mid-January 2022, which includes the key company financial reports from the first three quarters of the year.

Dr. Mayer concluded his analysis with two forecasts; one for 2022 and one looking ahead to 2026. "During 2022, sales of lasers and laser systems for the industrial markets will see greater than 10 percent nominal growth," he said, "with at least 5 percent due to GDP growth, and assuming at least 2.5 percent inflation." It is worth noting here that previous speaker Dr. Basu himself had predicted at least 5 percent global inflation during 2022.

Dr Mayer's 2026 forecast said that the sales value of industrial lasers and systems would have a CAGR of 8 percent, during the next five years.

2021 Global Market for Industrial Laser Systems in USD Billion.

MATTHEW PEACH

Making smaller microLEDs

Though there are challenges to be met, the future is filled with microLED displays, said Steve DenBaars, a professor of materials and of electrical and computer engineering at University of California, Santa Barbara (UCSB). At Photonics West on Monday, he focused on III-nitride-based RGB microLEDs for AR/VR applications, but also for handheld displays, wearables, and large-area displays.

All of these, DenBaars said, are driving demand for microLEDs of less than 10 μm. AR/MR needs sizes of less than 4 μm to meet size requirements of those technologies, whereas all other markets need less than 10 μm to meet cost requirements.

He said research at UCSB is attempting to address some key microLED problems, for example, efficiency drops as the microLED size decreases. These are due to the effects of sidewall damage that are more pronounced when device dimensions are smaller than 40 μm. These surface defects can be suppressed by sidewall passivation, usually via plasma-enhanced chemical vapor deposition. But DenBaars says his group has found atomic layer deposition (ALD) to be a better choice: ALD yielded uniform light emission among all microLED sizes.

His group also found that chemical treatments resulted in different sidewall profiles, especially potassium hydroxide (KOH) faceting of microLED sidewalls. MicroLEDs with ALD plus KOH resulted in the lowest light leakage, DenBaars said.

MicroLED brightness can diminish with size. Courtesy: Steven DenBaars, UCSB.

Other notable achievements in DenBaars lab: Through novel epitaxial growth and processing and transparent packaging, his group has achieved external quantum efficiencies as high as 58 percent at 450 nm for 40 x 40 microLEDs. They have demonstrated efficient microLEDs emitting in the blue to green at dimensions as small as 2 μm, and they have fabricated red indium-gallium-arsenide based microLEDs with efficiencies of 2.5 percent.

"The critical challenges of microLEDs, namely full-color scheme, decreasing pixel size, and mass transfer technique, need much development still for sub-10-micron AR/VR applications," DenBaars said.

WILLIAM SCHULZ

Corning upgrades glass for AR/VR applications

The glass and materials giant Corning has chosen the Photonics West exhibition to launch a new higher-index glass for augmented, virtual, and mixed reality (AR/VR/MR) applications that is said to create larger, clearer images and enable lighter, sleeker device designs.

The new glass features a refractive index of 2.0, enabling a wider field of view (FOV) and light transmission at blue wavelengths, claims the firm. The glass is a critical optical element in AR glasses and headsets, and used in diffractive waveguides.

"Optical advancements inherent in the glass take the augmented reality experience to the next level through larger, clearer digital content that creates more engaging and immersive user experiences," said the company, which is showcasing the new material at booth 1835 in the Moscone Center.

The new glass joins the company's existing AR/MR portfolio, which also features high-index compositions with refractive indices of 1.8 and 1.9. Corning has previously supplied the high-index glass for companies such as UK-based WaveOptics, which is now part of software giant Snap, Inc.

WaveOptics said previously that the flatness, refractive index, and parallelism of the waveguide glass produced by Corning are all crucial for ensuring image quality with low scatter and high contrast.

Compared with lower-index glass, companies designing AR/VR/MR glasses and headsets should now be able to achieve a larger FOV with fewer pieces of glass, meaning that their resulting hardware should be both lighter and cheaper to produce.

"Corning's 2.0 glass composition, as well as its comprehensive solutions for flatness metrology and precision laser glass cutting will further enable the AR/MR industry, bringing mass consumer adoption one step closer," the company said, adding that the new material was available in wafer diameters of 150mm, 200mm, and 300mm, in a range of thicknesses and with leading geometric tolerances.

David Velasquez, company VP and general manager at Corning Advanced Optics, added: "Our technologies bring the detail below the surface to life. Over the next several years, through new glass compositions, supporting capabilities, and innovative solutions, Corning will help enable the adoption of AR into our daily lives.

"These headsets require very precise, very flat glass in the eyepiece for a wide FOV and superior image quality, and our extensive knowledge of glass allows Corning to drive innovation in this application space."

MIKE HATCHER

Spex appeal: JBD and Tooz Technologies have combined a curved waveguide including prescription with a polychrome display engine featuring x-cube optics and a red, green, and blue microLED display panel. Credit: Tooz Technologies.

CURVED WAVEGUIDE ENABLES PRESCRIPTION AR GLASSES

Shanghai's Jade Bird Display (JBD), a participant in the SPIE AR|VR|MR event taking place in Moscone West this week, has teamed up with Tooz Technologies — a joint venture between Zeiss and Deutsche Telekom — to produce prescription AR glasses based around a novel curved waveguide.

Under the newly formed collaboration, JBD and Tooz say that they are the first to achieve the technological feat. "The combination of the color microLED display engine by JBD and the curved waveguide by Tooz enables sharp, full-color virtual screens while keeping a slim and stylish form factor and fulfilling the essential function — individual vision correction — of everyday glasses," they announced, with the first public demonstration of the glasses at AR|VR|MR.

Qiming Li. Credit: Joey Cobbs.

For the joint solution, JBD provides a display engine that combines three monochrome microLED display panels with an x-cube optic to create a polychrome display. The red, green, and blue 0.13-inch panels are aligned to the sides of a 5 mm x-cube, resulting in a total volume of just 0.72 cubic centimeters.

The JBD module is then attached to the curved waveguide lens by Tooz. "With several high-precision, free-form surfaces, the lens guides the light from the x-cube to the wearer's eye without the need for any additional separate optical elements," explain the two firms. The Tooz device is said to be the only curved waveguide lens on the market that allows seamless integration of vision correction.

"With the energy-efficient combination of waveguide and x-cube, the virtual information screens in the wearer's field of view can be multi-colored, allowing for a versatile visualization of the user interface," say the two firms. "Further, the screens are brighter compared to former displays while consuming less battery power."

That decrease in power consumption is said to allow for all-day usage of the smart glasses in a slim and stylish form factor — including prescription vision correction.

JBD CEO Qiming Li and Tooz CTO Frank-Oliver Karutz demonstrated the first results of the newly formed strategic partnership in a joint presentation in the Consumer Electronics session at SPIE AR|VR|MR Monday afternoon.

After his booth at AR|VR|MR proved a popular destination for visitors, Qiming Li was full of praise for the event. "We had also exhibited at CES this year but the volume and quality of leads here is much greater," he said.

MIKE HATCHER

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Disruptive technologies and optimization techniques among OPTO plenary talks

Photonic inverse design is rewriting photonics textbooks, says Professor Vuckovic, who described the technique at the OPTO Plenary on Monday. Fellow plenary speaker Dr. Andrea Blanco-Redondo described the importance of disruptive technology silicon photonics as its applications proliferate beyond communications.

"I am excited about all of them!" exclaims Jelena Vuckovic of Stanford University when asked about the current projects at her Nanoscale and Quantum Photonics Lab, which is making strides in scalable quantum and nonlinear photonics platforms in diamond and silicon carbide, and inverse designed integrated photonics. "I never work on a project unless I am excited about it, because my and my team members' enthusiasm is crucial for the success of our projects."

Jelena Vuckovic, the Jensen Huang Professor in Global Leadership at the Stanford School of Engineering, and professor of electrical engineering and applied physics. Credit: Stanford University.

At the OPTO plenary session on Monday, Vuckovic, the Jensen Huang Professor in Global Leadership at the Stanford School of Engineering, and professor of electrical engineering and applied physics, discussed how the inverse design approach can enable new functionalities for photonics, such as compact particle accelerators on chips which are 10,000 times smaller than traditional accelerators, chip-to-chip and on-chip optical interconnects with error-free terabit per second communication rates, and quantum technologies.

Andrea Blanco-Redondo, head of the Silicon Photonics Department at Nokia Bell Labs. Credit: Jayne Ion, Nokia Bell Labs.

Despite the progress of photonics over the past few decades, Vuckovic notes that we are nowhere near the level of integration and complexity in photonic systems that would be comparable to those of electronic circuits, thus preventing the use of photonics in many applications.

"Photonic inverse design is rewriting photonics textbooks," Vuckovic told the Show Daily. "Optimization techniques are crucial for making scalable integrated photonics for any applications. I would like to see it expand to fast design of large three-dimensional structures and have it accessible to everyone — without the need to pay large fees or buy expensive hardware or get training in photonics.

"We are working on addressing all of these. We already have an open-source version of our software for inexpensive gaming GPUs posted on github, which many people around the world are using. New, much more powerful software versions from our team will be coming there soon," Vuckovic added.

Disruptive technology enables scientific breakthroughs

"I am very fortunate to lead a team of brilliant researchers and real experts in a variety of fields in integrated photonics," says Andrea Blanco-Redondo, head of the Silicon Photonics Department at Nokia Bell Labs. "My role is to guide them and support them to achieve their research goals. At the same time, I lead my own research lines on nonlinear and topological photonics."

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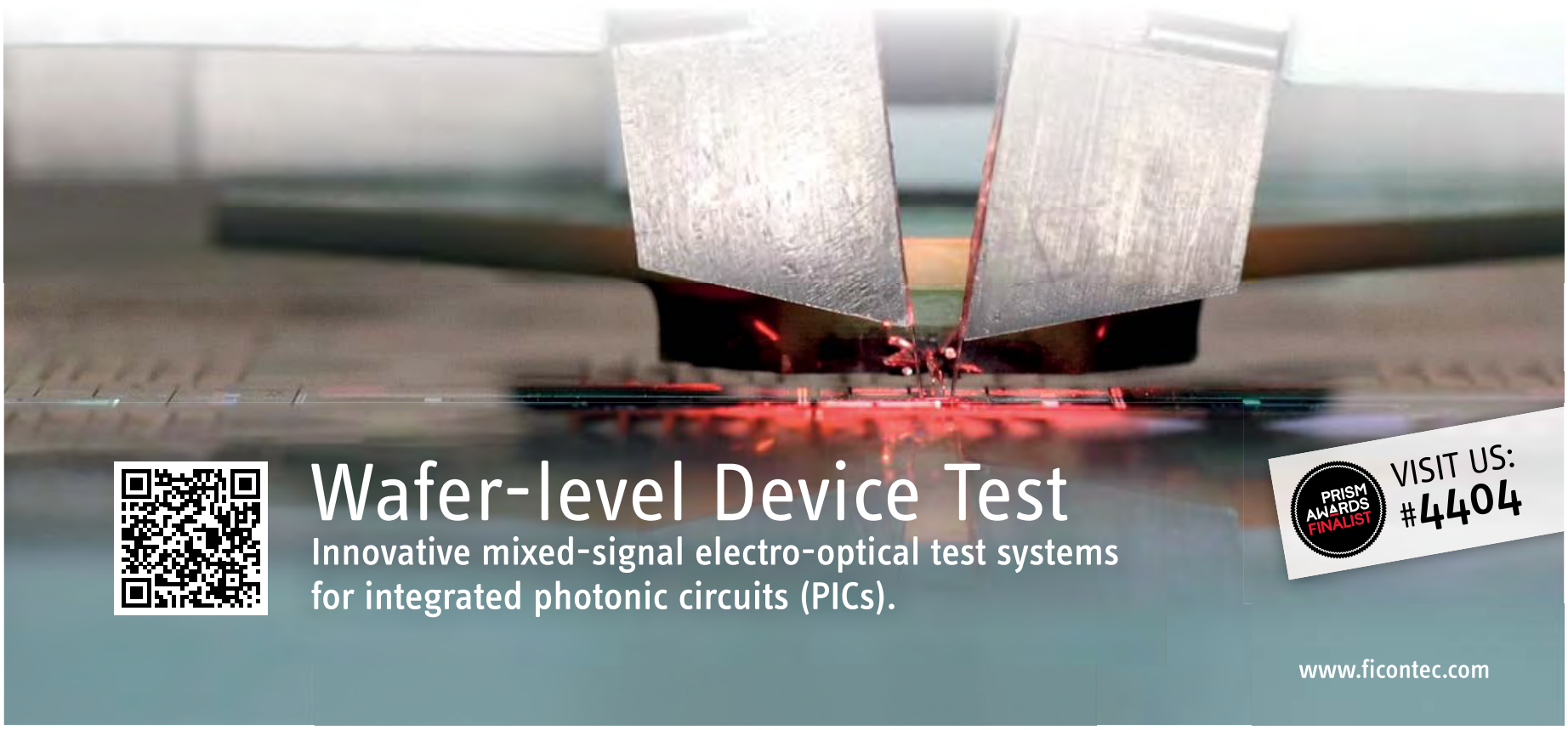

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Lawrence Livermore National Laboratory's National Ignition Facility laser system. Credit: LLNL.

LASE plenary talks explore new laser-based tools, high-Q metasurfaces, and photonic quantum systems

In August (2021), a record-breaking shot with 1.3 megajoules of fusion yield was achieved on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL). This experimental result, decades in the making, was a significant breakthrough for laser-driven inertial fusion.

At the LASE Plenary and Hot Topics session on Monday, Tammy Ma, the Advanced Photon Technologies Program Element Leader for High-Intensity Laser High Energy Density Science at LLNL, discussed how these game-changing results are laying the groundwork to explore laser inertial fusion as a path for clean energy and energy security.

Lawrence Livermore National Laboratory physicist Dr. Tammy Ma. Credit: LLNL.

Moving into the terahertz domain

"Right now, the high-power, ultrafast sources in the THz domain that we developed in the last few years are a unique 'niche' development that I find most exciting," says Clara Saraceno, who leads the Photonics and Ultrafast Laser Science (PULS) group at Ruhr University Bochum. "I find it really interesting to see what new applications will unravel or what 'old' problems these 'new' laser-based tools could help to solve."

As part of the LASE Hot Topics session, Saraceno discussed how the demonstration of table-top sources of few-cycle THz radiation with extremely high average power has been enabled by progress in high-power ultrafast laser sources.

Saraceno notes that research and development of new laser sources — and more widely, other light-based sources — is critical for solving technologically and scientifically difficult problems. This doesn't only relate to

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OPTO Plenary

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Blanco-Redondo was the third plenary speaker at Monday's OPTO session where she conveyed the importance of silicon photonics, not only as a disruptive technology in data centers and access networks, but also as an enabler of fundamental scientific breakthroughs.

"Silicon photonics offers exquisite control over a multitude of parameters," Blanco-Redondo told the Show Daily. "For instance, in our lab we have used control over dispersion and nonlinearity to create a new kind of soliton — the pure-quartic soliton. While controlling the topological properties in silicon lattices has enabled us to robustly generate and propagate quantum photonic states on-chip."

In her talk, Blanco-Redondo covered recent developments in topological quantum photonics, which studies topological phases of light and leverages the appearance of robust topological edge states. These developments included her lab's recent unveiling of topology as a degree of freedom for photonic entanglement, which could lead to more robust and complex entangled states in integrated platforms.

"I am thrilled about our latest findings in leveraging higher-order dispersion to unlock new possibilities with nonlinear devices, such as soliton pulses with higher energy than theoretically predicted for conventional solitons," says Blanco-Redondo. "I would like to see topology unleashing its potential for real applications. It would be fantastic to see topology having a true impact on large scale photonics integration and photonic quantum computing."

KAREN THOMAS

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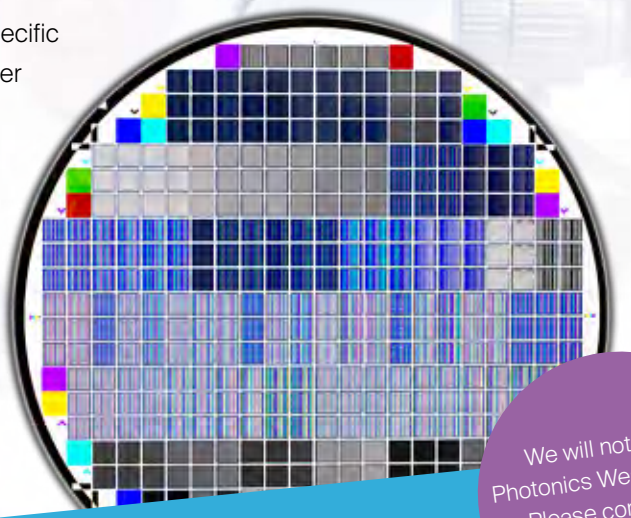

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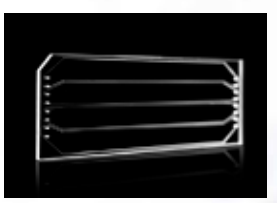

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Photonics West meetup to showcase the skills of Black scientists

Black in Photonics initiative is raising profile and awareness of under-represented industry talents. Founder Michael Joseph Williams hosts today's networking and community-building event at the Career Hub.

"It's critical to have not just more representation, but to also generate a sense that we belong here," says Michael Joseph Williams. "We're talking about images — optics, right? — and we need people to see that there *are* Black scientists in optics and photonics."

Williams is the lead organizer for Black in Photonics and is working to increase the visibility and opportunities for Black researchers, engineers, and students in the community. In late 2021, Williams reached out to SPIE event coordinators and a plan for an informal meetup at SPIE Optics & Photonics — for many, the first in-person meeting since March of 2020 — took life. In this case, the ability to organize and reach people online proved to be a real asset: Williams' proposal had an enthusiastic and engaged response, with the pleasing outcome of an in-person event, which included much of SPIE leadership. Now, Williams is looking forward to hosting a second in-person gathering this week during SPIE Photonics West.

The impetus to establish Black in Photonics, Williams says, was driven by his experiences at scientific meetings as an attendee and not seeing more people that looked like him. Forming Black in Photonics was an opportunity "to bring everybody together and let them know that they're not alone," he explains. "I'm tired of feeling like a token; I want there to be more of us present. There is a plethora of Black scientists who are active in the optics community and there are Black students who want to be involved in optics, but they don't always feel that they are particularly supported. I'm trying to fill that role: I'd like to bring them together, to consolidate us if you will, so that *we* can see how much representation there really is." That, Williams believes, will go a long way to inviting others to feel welcome, included, and acknowledged.

Williams, born and raised in Philadelphia, got his BS in physics from Morehouse College. He then participated in Fisk University's Fisk-Vanderbilt Master's-to-PhD Bridge Program, tailor-made to help underrepresented groups and minorities achieve PhDs. Williams pursued his doctoral studies at Delaware State University under the direction of Renu Tripathi, the inaugural winner of the IBM-SPIE HBCU Faculty Accelerator Award in Quantum Optics and Photonics. His research focused on investigating the linear/nonlinear efflorescent optical properties in nano-diamonds, studying how to properly engineer nano-diamonds for different photonic applications. And it was there that his advocacy work also took new shape: "I love doing optics outreach," notes Williams. "One of the responsibilities I had at Delaware State as part of the SPIE Student Chapter was doing outreach projects — science demos at elementary schools, libraries, science fairs. I loved all of that."

Black In Photonics founder Michael Joseph Williams. Credit: SPIE.

Michael Joseph Williams with Professor Anita Mahadevan-Jansen, SPIE President, 2022. Credit: SPIE.

Since early 2021, Williams has been working as an engineer scientist for Boston Electronics, an optics-distribution company which provides advanced electro-optical solutions and application support in cooperation with various optics companies. "I feel really blessed to be there," he says. "I get to work with people who have been in the optics industry for years. I love working in optics because I'm always learning, and I really appreciate the human interaction that this applications specialist job entails — I enjoy helping people achieve what they want."

Which brings us back to Black in Photonics, a burgeoning community of active, collective voices. "In conversations regarding racial inclusion and equity, I hope that people will be able to listen to Black people's stories and not try to interpret their own stories for them. I feel that once we are able to continue on that road, then we can definitely have the visual optics of being a truly multi-ethnic society with SPIE. That's my wish — to have not just representation but to have more Black plenary speakers, to have more Black scientists give presentations on papers they've published, and to have the same access to the different opportunities and resources that our other colleagues have. We just want to have an equal seat at the table and to be valued as such."

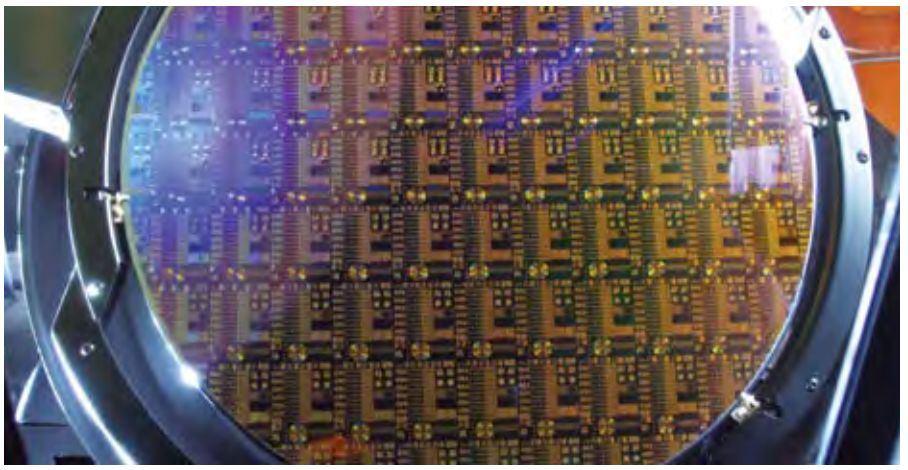
Join Williams and fellow photonics colleagues and allies for a networking and community-building Black in Photonics meetup at SPIE Photonics West: 26 January, 5:30-6:30 PM PST at the Career Hub, Moscone West, Level 1.

DANEET STEFFENS

Metastructures progress from research hope to commercial hit

Ten years ago metamaterials were a research novelty but are now reportedly garnering interest from smart phone manufacturers. Meet the scientists commercializing the remarkable technology.

When Professor Federico Capasso published his seminal paper on metamaterials, 'Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction' in late 2011, he was astonished by his fellow researchers' interest. It had all started with a request from Harvard atmospheric chemist, Professor Jim Anderson, who had been flying quantum cascade lasers in planes to study methane plumes. Anderson now wanted to study high altitude cloud chemistry with a drone, and asked Capasso if he could collimate the laser without a lens to save precious space in the small craft.



Near infrared metalenses on a wafer from Metalenz. Credit: Metalenz.

"I was thinking this is a nutty question but then bandied up with my post-doc — we patterned a flat collimating lens directly onto the laser facet, and that was the beginning of metaoptics," says Capasso. "We continued to play, published the paper and I was shocked at how it took off — it was as if people had suddenly seen the light."

A decade and more than 6000 citations later, the *Science*-published research holds firm and the field of metasurfaces and metaoptics is awash with activity. From spin control of surface waves and advanced image processing to beam steering and gallium nitride light-emitting metasurfaces, Photonics West is set to showcase the potential and breathtakingly broad application of metamaterials.

For his part, Capasso is looking forward to seeing the latest results on broadband achromatic metalenses, a research area close to his heart. In 2019, he and colleagues demonstrated achromatic metalenses, tens of microns in size across, that covered much of the visible light range. They have since delivered 2 mm-sized achromatic lenses that focus RGB wavelengths without aberrations, developing a miniaturized display for AR/VR applications, and are trying to fabricate larger lenses that operate across visible wavelengths. As Capasso highlights: "We're seeing more and more research taking place here [on aberration]."

Indeed, at Photonics West in the session on High Contrast Metastructures XI (Wednesday, 3.00pm), Dr Calvin Hooper from the University of Cambridge, UK, will describe his computer simulations to explore how metalens design can overcome achromaticity. His work follows a Cornell University study that explored how thickness and refractive-index contrast limit a metalens' ability to eliminate chromatic aberrations. In the same session, Dr Andrew McClung, UMass Amherst, will detail a large achromatic metalens doublet that is corrected over 800-900 nm, (Thursday from 08.00 am), while Professor Juejun Hu, of MIT, will look at the intricate design trade-offs in wide field of view metalenses, for aberration suppression (Wednesday from 08.40 am).

Beyond aberration, Capasso is also presenting work on multifunctional metaoptics, including metagratings and computer-generated holograms, and will showcase a polarization-sensitive camera that measures depth from image defocus in a single-shot. Inspired by the retinae from the eyes of jumping spiders — which have remarkable depth perception — a metalens splits light to form two differently-defocused images side-by-side on a photosensor. An efficient algorithm then analyses the data to build the depth map. The compact device is less complex than today's depth cameras — which require a rotating polarizer and analyzer set-up — and could soon find its way into VR/AR headsets.

"Hardware and software co-design is an important trend that led us to this depth camera — which has a much lower computational cost in terms of flops than conventional depth sensing," says Capasso. "I also think polarisation is an area where metaoptics has absolutely no competition as the existing technology is just so complex."

But research and development aside, metaoptics look to be on the cusp of commercialization with the first application being the hundreds-of-billions-of-dollars smart phone market. Single metaoptics lenses, fabricated on silicon wafers, have the potential to replace the several refractive lenses currently used in today's mobile devices, eliminating the so-called smart phone camera bump.

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LASE Plenary continued from page 09

the THz domain, but to most applications in other regions of the electromagnetic spectrum as well.

"In many cases, sources research is underestimated in its difficulty and usefulness by people doing the applications," says Saraceno. "This means that more 'blue-sky' research (where 'real-world' applications are not immediately apparent) in exclusive source development should be made possible, and that more collaborative work between source developers and application experts should become the norm."

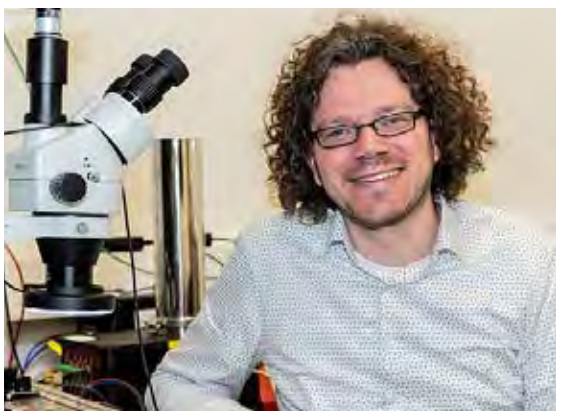
Saraceno believes the key for continuing the advance of high-power ultrafast laser technology will be in the combination of technologies, meaning having more 'hybrid' systems to reach a desired goal. She would like to see more collaboration between laser source experts and applications, and more academic work in this area.

"Most importantly," says Saraceno, "I would like to see these extremely high average power systems be more often brought to applications where they can shine."

Photonic quantum systems

Plenary speaker Michael Kues, head of the research group "Photonic Quantum Technologies" at Leibniz University Hannover, reviewed approaches for the efficient realization of quantum frequency combs in on-chip waveguide structures and micro-resonators.

"I would like to emphasize that the multi-mode nature of the photons' frequency degree of freedom, in the form of so-called quantum frequency comb systems, together with further exploration of elaborated manipulation elements, can be a powerful approach to develop scalable quantum systems for various application scenarios in communication, computing, sensing," says Kues. "From the side of technology, this approach is compatible with and can directly benefit from already developed state-of-the-art telecommunication devices and integrated photonic fabrication."



Prof. Michael Kues, head of the research group "Photonic Quantum Technologies" at Leibniz University Hannover. Credit: Leibniz University Hannover.

Kues adds that he would one day like to see further advancement of photonic quantum systems towards large scale solutions, capable of implementing and accelerating required computations in material research, drug development, climate models, and AI.

Lenses beyond limits

During her Hot Topics talk, Jennifer Dionne, Senior Associate Vice Provost of Research Platforms at Stanford University, shared how nanophotonics can address challenges in global health. Key to this work is her lab's recent development of high-quality-factor (high-Q) metasurfaces. These high-Q metasurfaces strongly localize light in the near field, while also precisely directing optical transmission to the far-field. Dionne described how these metasurfaces enable multiplexed and low-cost genetic screening and rapid antibiotic susceptibility testing of bacteria, including tuberculosis.

"I think metasurfaces hold enormous potential for future *networks*, spanning health, sustainability, and communications," says Dionne. "The useful information density of a network scales with both the number of elements and the number of connections. For optical networks, considerable effort has been devoted to miniaturizing photonic components, in order to increase the number of *elements* in the network."

With her lab's development of high-Q metasurfaces, an alternate strategy for scaling photonic networks is being created: increasing the number of connections between wavelength-scale components. Dionne points out that although the diffraction limit sets a bound on the number of optical elements that can be included in the network, there is no limit on the number of diffracted channels.

Producing multifunctional surfaces

"In the last 20 to 30 years, there has been enormous progress in the utilization of laser-based technologies, in particular using short and ultra-short pulsed laser sources, for addressing relevant scientific questions related with high-precision processing of materials as well as with the functionalization of surfaces, says Andrés Fabián Lasagni of TU Dresden and Fraunhofer IWS. "However, typical drawbacks for these technologies have been the high cost of the laser sources and the relatively low productivity." Lasagni notes that the situation is changing with the introduction of new high-power laser sources, which can significantly reduce processing times and production costs. However, this will only be possible if new optical systems and strategies are developed to manage these higher powers.

Prof. Clara Saraceno, who leads the Photonics and Ultrafast Laser Science (PULS) group at Ruhr University Bochum.

At TU Dresden, Lasagni is chair of the Large Area Laser Based Surface Structuring group, which focuses on the development of functional surfaces. At Fraunhofer IWS, he is director of the "Center for Advanced Micro Photonics," that strategically coordinates with activities at TU Dresden in various research fields such as photonic-based in-line monitoring and advanced laser micro structuring.

For his LASE Hot Topics talk, Lasagni provided an overview of laser-based fabrication methods and how they can be combined to produce surfaces with multi-functional surface properties. Also, how the combination of well-defined and periodic structural elements with different feature sizes can be used to increase the long-term performance of surfaces.

KAREN THOMAS

With lidar, these smart turbines could spot gusts a few miles away and respond accordingly. Photo courtesy of Pixabay.

Photonics for Net Zero: much more than photovoltaics can help save our planet

The manipulation of light holds great promise for slashing energy consumption at data centers, for optimizing wind turbines, for growing crops indoors, and for much more. And there are plenty more unsung hero technologies as well.

Ask anyone to identify a photonics technology that they think is helping the environment, and the answer might typically be "photovoltaics." Silicon that generates electricity by mimicking the process of photosynthesis is, as everyone knows, a key player in the push to eliminate CO_2 emissions.

So today (Wednesday) at Photonics West, photovoltaics will take the stage during the session Photonics for Net Zero, where Professor Karin Hinzer from the University of Ottawa will deliver an update on developments across her field of research into new materials, light sources, detectors, solar cells, grid integration, voltage converters and other areas.

John Lincoln, CEO of the UK's Photonics Leadership Group. Credit: Courtesy of John Lincoln.

But when it comes to saving the planet, photovoltaics and the other well known star — energy efficient LED lighting — are not the only heroes.

The manipulation of light has plenty of unsung technologies that are truly contributing either to the reduction of energy consumption, to the operation of low or non-CO_2 emitting generation processes, or to both.

"If you think about how does photonics impact sustainability, there are certainly three key axes," notes session chair John Lincoln, owner of business consultancy Harlin Ltd in Salisbury, England, and CEO of the Photonics Leadership Group, a UK industry association. While power generation is certainly one of the three, so, too, is energy use, as is the reduction of waste, he notes.

Whether it's the optimized running of wind turbines, the energy efficiency of data centers, the maintenance of underwater high voltage cables, the use of artificial light to grow crops, or any number of others applications, photonics are playing a key role in the quest to protect Planet Earth.

Take data centers, for instance. Who amongst us goes a day without using one? Communications, business, banking, shopping, entertainment, media, highway navigation, you name it — it's all online, in the cloud, zipping through wires and the ether, and reliant on the electricity that feeds all the incumbent digital processes of storing, protecting, fetching, analyzing, and delivering. The Paris-based International Energy Agency estimates that data centers account for 1% of the world's electricity consumption — a figure regarded by many as conservative.

Be it 1%, 5% or more, the point is: Data is the new oil indeed! Add in the constant ratcheting up of high performance computers and the intensified processing for the artificial intelligence that is rapidly infiltrating human life, and you get the picture. Our IT-dependent lives are a monumental challenge to the environment.

The voracious power needs of the data economy and the resulting CO_2 emissions is certainly something that the IT industry is paying attention to. Thus, over the last decade or two, there have been plenty of headlines about locating data centers in cool climates like Iceland and Sweden — chilling is a big part of the energy equation and in some of these locations the energy sources themselves are renewable — and about other ecologically-minded data center architectures.

Couples Act

Short of the big sweeping picture of data center design and location, there is plenty of work evolving on how to make the inner workings of big computers and systems more efficient. Much of the effort relates to the processes involved in moving around optical signals.

For example Meta — the computing giant formerly known as Facebook — is convinced that shortening the distance in a data center between an optical switch's transceivers and its central processing chips could considerably slash overall switching energy consumption.

Switches connect the many servers in a data center. In today's editions, the transceivers tend to be about 30 to 40 millimeters away from the central chips, also known as the ASICs.

Vincent Zeng, a supplier quality engineer for optics and networking in Meta's sourcing and operations engineering group, will speak at today's session about the prospects for suppliers to move them closer together by co-packaging them on a common circuit board.

Co-packaging would not only make the process inherently more efficient, but it would also eliminate the need to run power separately to both the transceiver and the ASIC, Zeng points out.

"That would be a huge service cost," says Zeng.

So Meta and many of the world's other large data center users (round up the usual suspects!) are working together on a standard that would specify how to spot defects in laser chips during the fabrication stage — an advance that would cut down on failures during operation, and thus minimize any eventual need for costly board throw-aways.

"We need to take action to fix the problem before it is born," says Zeng. "If we do not address this issue in the beginning, we'll end up getting into big trouble."

Zeng is working with cohorts at the other large end user companies to submit a proposal to standards group Telcordia in the first half of 2022. He hopes that Telcordia would then implement the idea as a standard.

Where VCSELs trump silicon

While transceiver and ASIC co-packaging portends promising reductions in data center power use, it is by no means the only photonic technology that could lead to such improvements.

At today's Net Zero panel, Vipul Bhatt of II-VI Inc. will provide insights on another way that laser technology could improve computer efficiency.

Inside any computing system, "it takes energy to carry information from A to B," notes Bhatt, who is vice president of datacom marketing for the Saxonburg, PA-based materials and optoelectronics company. "There's no way around it. The job of an optical link is to consume as little as you have to. Maybe the best we can do is make efficient optical links. As speed goes up, and distances go up and hardware has to burn more and more energy, maybe optics can do better."

Indoor farming: Crops growing under spectrally optimized LED lights can help feed people and save water. Credit: Signify.

While plenty of co-packaging work is underway in the supplier community, there's a potential problem brewing. The directly modulated lasers (DMLs) in use in today's distanced schemes are designed to be thrown out and replaced when they fail. The disposable approach would be untenable with a co-packaged board, because it would require the replacement of the entire board and its contents, including the ASIC.

continued on page 19

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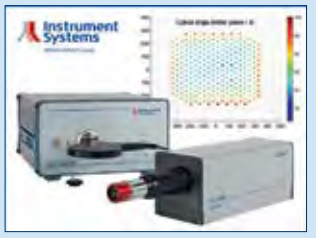

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polymer optics perfected

Metastructures continued from page 12

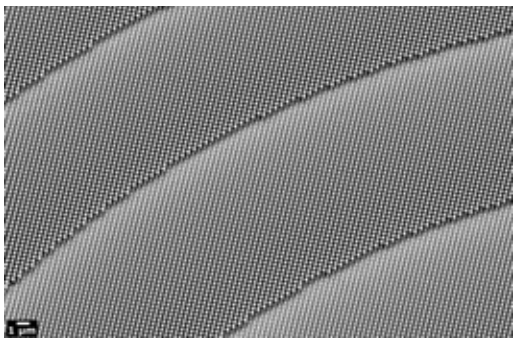
Investment target

One company set to capture market share here is NIL Technology. In 2021, the Danish firm added €26 million to the many millions of euros it has already won in venture funds and is ready to mass produce its highly efficient, flat near infrared (NIR) metalenses, following years of development.

Depending on the application, the company's so-called meta optical elements comprise arrays of pillars to sub-100 nm diameters with vertical sidewalls. A master metalens is manufactured via electron beam lithography and then mass-manufactured using nanoimprinting. And NIL Technology CEO and Founder, Dr Theodor Nielsen, also highlights how his company can generate a design and make a prototype in less than two weeks.

"We are ready to serve the mobile phone industry and are building up capacity now," he says. "The commercial interest is huge, and our short-term [market] is 3D sensing for mobile phones on both the front-facing and world-facing sides."

"Metalenses reduce the number of elements in your optics system, are easier to assemble and provide more functionality," he adds. "They give you the opportunity to rethink how you define your optical system and hold the promise of the perfect lens — perfect in the sense that they offer significantly more than the [refractive] lenses we have today."



Scanning electron microscopy image of a meta optical element from NIL Technology. Credit: NIL Technology.

Nielsen's colleague and Head of Optics at NIL Technology, Dr Ulrich Quaade, will describe the technology in the 'Photonic and Phononic Properties of Engineered Nanostructures XII' session at Photonics West (Wednesday, 4.40 pm), and will look at the company's NIR camera module, which uses a 940 nm single metalens and NIR sensor. He will also provide insight to how the metalens hits its 94% focusing efficiency — measured as the optical power transmitted to the focal spot divided by incident power on the lens element.

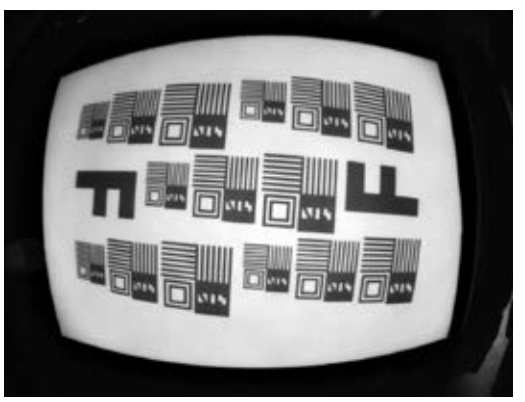


Image from a near Infrared imaging system using a single meta optical element surface designed for 940 nm wavelength by NIL Technology. Credit: NIL Technology.

"I'm not aware of anyone that has claimed efficiencies at this level," says Nielsen. "So we've addressed the efficiency, we have a route to mass production... I believe we are successful as we have all of our design, fabrication and characterisation in-house, and I'm sure metalenses will be in smartphones in one to two years."

NIL Technology is not alone in its commercial aspirations. US-based fabless semiconductor business, Metalenz, the spin-out of Capasso's Harvard group and headed up by Dr Robert Devlin, won $10 million in funds last year from firms including Applied Ventures — the venture capital arm of Applied Materials — and Intel Capital to commercialise metaoptics technology. The company also unveiled its metaoptics-based dot projector for both structured light and time of flight 3D depth sensing in mobile phones, and signed a deal with STMicroelectronics to manufacture metaoptics technology for next-generation smart phones and other applications.

Mass production is imminent and as Devlin commented when Metalenz struck the STMicroelectronics deal: "We want to get metasurfaces out there in a very rapid way... in all of the places that you need 3D sensing."

Unsurprisingly, Capasso is also very excited. "We have had many OEM suppliers, who are working with cell phones, talking to us at Metalenz, and [according to] our roadmap, you will see products with our actual metalenses in two to three years ," he says.

"I believe that the smart phones of the future will become miniature spectrometers for sensing," he adds. "We are beyond the point of no return now, and metaoptics will capture significant market share in optics primarily in consumer electronics, where you benefit from making things thinner."

REBECCA POOL

Net-Zero Photonics continued from page 14

Bhatt will address the use of lasers in High Performance Computing (HPC) and in machine learning systems, noting that in certain instances, it's time for those sectors to move away from lossy silicon photonics, and to instead implement more energy efficient multimode vertical cavity surface emitting lasers (VCSELs).

A prime example: when information is traveling on the order of 10 meters from, say, memory to processor in an HPS farm, then multimode VCSELs could slash energy consumption by 30% on their own, and by up to 50% when considering that they could eliminate the need for other power consuming components, such as re-timer circuits and fancy modulation schemes.

The same holds true in machine learning computer centers, where, again, connections might travel tens of meters between processors and enormous data banks. Likewise, in some large data centers, server to server connection can be sometimes be around 10 meters.

"High performance computing, machine learning systems and some server connectivity applications, that need tens of meters, not hundreds of meters or kilometers reach. In that case, I think the multimode VCSEL-based optical links are the most energy efficient," says Bhatt.

The single mode silicon photonics that today's system use, are, according to Bhatt, overkill. "They're optimized for slightly longer reach, even if it's two kilometers or ten kilometers, which some may consider not so long a reach, but it's way longer than the ten or twenty meters you need for these three applications."

Smarter use of photonics could slash the voracious energy consumption of data centers. Photo courtesy of Pixabay.

And given that silicon photonics is inherently less efficient, the logical choice should be multimode VCSELs. "Silicon has to do the job of modulating light and guiding it," notes Bhatt, pointing out that those tasks both entail energy losses.

"And the source of light is not yet in silicon," he adds. "Silicon has failed to produce light. It makes a very inefficient laser. The laser is still the indium phosphide compound of traditional lasers." While engineers have tried "all sorts of tricks" to couple the laser and the silicon, the process has rudimentary inefficiencies, Bhatt notes.

VCSELs, on the other hand, are lasers in their own right. And while a VSCEL "doesn't produce a lot of power, it doesn't need a lot of power," Bhatt points out. Another advantage: the circular shape of a VCSEL pairs well with the cylindrical profile of fiber optics, which enhances efficiency.

Lidar harnesses the wind

To state the obvious, the "green" picture of any data center, or of any use of electricity, improves if the energy source itself is renewable. To that end, the photonics industry is hard at work not just on photovoltaics, per Hinzer's work at Ottawa, but in plenty of other ways.

"Things that photonics can do in terms of net zero are about sensing and imaging — the tools to monitor the environment, to make sure that when we implement new technologies, that we are implementing them in the most efficient and effective way possible," says Simon Andrews, executive director of Fraunhofer UK Research Ltd.

For example: wouldn't it be great if wind turbines could be optimized by locating them in precisely the right spot to catch the wind, and to alter their blade angles and other aspects depending on conditions at any one time? After all, the wind is a fickle thing, constantly changing direction, velocity and so forth.

At the Net Zero panel, Andrews will describe some of the laser lidar (light detection and ranging) technologies that his group has developed to do just that.

"We've made a variety of systems for the wind energy industry to make sure that they're surveying the wind before they decide where to put the turbines," says Andrews. "Putting them in the right place is vital, whether it's a complicated urban or rural environment, or even at sea, putting them in the right place is very important. And then once you've installed one, how do you know it's operating properly? You measure the electricity that's coming out of them, but you have to measure the wind that's arriving at the turbine. The only effective way to measure the wind is with lidar."

Fraunhofer UK, based in Glasgow and an independent affiliate of Germany's Fraunhofer-Gesellschaft, develops technologies that it licenses to commercial entities, largely through its Fraunhofer Centre for Applied Photonics. Its lidar wind detection systems range from what Andrews calls "cheap and cheerful" to sophisticated gear that ascertains wind conditions 5 kilometers away, providing time to adjust the yaw of the blades so that they are pointing directly into the wind when it arrives, or to shut down the turbine completely if the wind is going to be powerful enough to damage the turbine's gear box. Lidar technology can also help alter the angle of the blades, which is a different aspect than the yaw.

This "triple lidar system" from Fraunhofer intersects three beams to together scan the full volume of wind and help determine exactly where to locate turbines. Photo courtesy of Fraunhofer Centre for Applied Photonics.

"With turbine blades describing a circle of up to 200 meters now, the wind is very very complex," says Andrews. "It can be going in opposite directions at the top and the bottom and the left and the right of these things."

For operational applications, Fraunhofer mounts lidar systems on the nacelle — the cylindrical portion of a turbine in the center of the blades that houses generating components. For early stage locational applications, ground based lidar aims at the sky to help determine how features such as hills and buildings affect the wind patterns in a specific areas. "You need to work out the windiest place to put them," says Andrews.

A wind lidar system works by reflecting light off of aerosols in the wind and looking for Doppler shifts. In a general sense it is similar to lidar reflecting off of cars and other solid objects for vehicular navigation, except getting it to work reliably with aerosols is a greater challenge.

It is a far more effective means of wind measurement than the traditional method of using anemometers — the opened half-globes, or cups that typically twirl around at the end of a stem and have been around for hundreds of years.

"Cup anemometers just take a single point of information, they don't give you information about the full volume of the wind," says Andrews. Describing wind as "a turbulent melee of veers and sheers," he notes that lidar provides the far reaching and three-dimensional view necessary for an effective analysis of a full volume. It would take thousands of anemometers to do the same job.

While lidar is more expensive — the Fraunhofer systems will range from $10,000 to $100,000, "you save vast amounts of money through the extra electricity that's generated, so these will pay for themselves in no time at all."

The are some non-Fraunhofer systems already on the market to help determine turbine location. Fraunhofer is currently well into trials of what it considers its more advanced technology with commercial companies in the North Sea. It already has users of the operational lidars mounted on turbine nacelles; those systems range in size, with the largest equivalent to the dimensions of a microwave oven.

Big squeeze continues

Meanwhile, Fraunhofer is continuing to develop other photonics with a view toward "net zero". For instance, its laser-based fiber optic sensing systems can detect damage to the undersea cables that connect offshore wind turbines to land. The systems monitor movement, pressure and temperature, prompting maintenance alerts that help avoid costly failures and replacements.

And in another walk of sustainability, Fraunhofer is developing LED lighting systems that can be tuned to optimal frequencies for different crops in the indoor vertical farming industry, which as Andrews notes has the potential to reduce water consumption by a factor of 250 times compared with outdoor growth.

Back amongst the celebrity technologies of photovoltaics and LEDs, the march of progress continues.

"Those two aren't done," says Andrews. "Every one or two percent in efficiency that we can squeeze out of solar cells and lighting are absolutely vital."

Whether the industry can squeeze all the way to zero remains to be seen. But as today's panelists will illustrate, the game is on.

MARK HALPER

Photonics in the early days of the quantum age

New apps and new gaps are emerging as the global industry takes shape.

Suddenly the excitement about all things quantum is mounting all along the ecosystem from labs to market sectors. And all along this route, photonics seems to be a key enabling technology.

Photonics West audiences are this week learning what's up, behind the scenes, as products are proliferating in this young marketplace that will, one day, be a multibillion-dollar industry. Three panelists will delve into quantum market issues at a keynote event at 9 a.m. on Wednesday, launching the Quantum West activities on the Quantum Hub Stage in San Francisco.

They include John "Jay" Lowell, senior technical fellow in Research and Technology at The Boeing Company, in its Disruptive Computing and Networks section; Celia Merzbacher, of SRI International, where she runs the Quantum Economic Development Consortium, or QED-C; and Mark Wippich, an entrepreneur and consultant who is host and sparkplug for the popular Quantum Marketplace on-line events presented by QED-C.

QED-C is supported by the US National Institute of Standards and Technology (NIST) and more than 170 industry, academic and other members and is managed by SRI International. Merzbacher advises several US quantum research centers, including the Quantum System Accelerator and the Superconducting Quantum Materials and Systems Center.

Innovations, the experts say, range from specialized optical features to new capabilities for lasers, to new cables to connect sensors, to ways to test the properties of materials.

Jay Lowell is senior technical fellow in Research and Technology at Boeing. Credit: Boeing.

On the research frontier, the most imminent market impacts will be in the quantum sensor domain, Lowell said in a phone call from his Boeing office in Fairfax, Virginia. And optics and photonics research "will be crucial to those breakthroughs." The quantum sensors are key, he said, and will be enabled by new photonic components, powered by photonic systems, employing lasers, modulators, frequency converters and filters.

How it all works

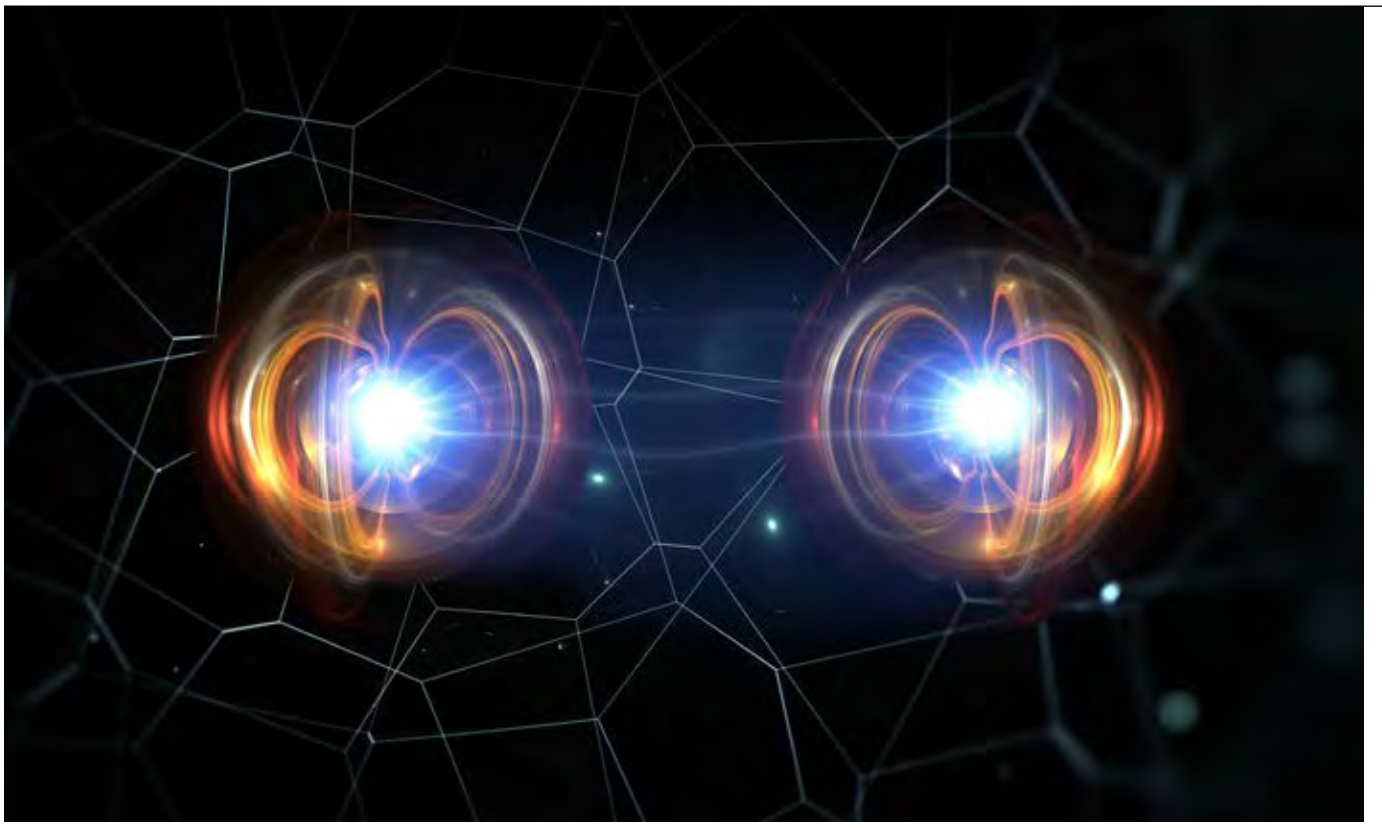
For example, Lowell spelled out one challenge. "When you make measurements of atoms, or quantum dots, or vacancy centers, you need to make a precision measurement of those quantum systems.

"You need to use a laser to probe an atomic system, and get a precise measure of a frequency. In turn, that frequency measurement can be converted to an electric field measurement, or a magnetic field, or to some inertial force.

"Those kinds of measurements are fundamental — magnetic, electric or inertial — those three underpin all the sensors on the market today. And classical sensors work, but not as precisely, not as accurately as will quantum sensors."

More precise quantum sensing

New quantum sensors will be more precise with their specific measurements. "That improvement in precision will allow us to see things that can't be measured by



QEDC's quantum objectives range widely from new capabilities for lasers, new ways to connect sensors, to ways to test the properties of materials — and more. Credit: AdobeStock.

classical sensors," Lowell said.

He described why The Boeing Company is interested in measuring inertial forces. "They make up the core elements of navigational systems, in almost all of our platforms," he said, "aircraft, submarines or underwater vehicles, and satellites. All of them use inertial navigational systems. We are concerned about having to act where an adversary is trying to deny us access to GPS."

And better quantum inertial sensor systems will mean less dependence on GPS and that, Lowell said, "is good for our government customers."

Although some gaps remain, the supply chains are already delivering many new features designed to perform at ultra-low temperatures, near absolute zero.

Just take a look at the QED-C site, under that consortium's Quantum Marketplace menu, and you'll see the details on innovations from more than 100 companies already on board with products. They display a wide range of skills and market items.

We asked Merzbacher how the Quantum Marketplace (QM) members who speak at webinars hope to benefit from those appearances. "QED-C members who present at the QM webinars are able to showcase their company's products and capabilities," she said.

"Those who attend learn about suppliers in the quantum supply chain. As a result of the webinars, suppliers have found new customers and collaborations have been initiated."

The categories of marketplace companies on display at the QM site include: applications and systems: ranging from AOSense to Zapata Computing; software: from IBM to Vapor Cell Technologies; hardware components: from ColdQuanta to Quantum Opus; services: from JanisULT to US Advanced Computing Infrastructure Inc.; and End Users: from Montana Instruments to Super.tech Labs.

In the first year of webinars, the QM team presented QED-C members speaking about a wide range of topics including lasers, quantum sensors, cryogenic technologies, entanglement, quantum timing, fabrication services, through to RF/microwave control electronics.

"The audience has been growing," Merzbacher said, "and the webinars are now available to the public. We hope that reach will continue to expand." Spotlight videos from each webinar are posted on the Quantum Marketplace website and are available on YouTube.

In addition to the webinars, QED-C has other activities under way to further its goals of enhancing the quantum marketplace, Merzbacher said. They will focus on:

- Benchmark tools for measuring progress (the first published tool is for benchmarking a quantum computer's ability to run specific algorithms).
- A model/tool for prioritizing investments in quantum-enabling laser technologies.
- Evaluating and strengthening the quantum supply chain.

Research and development

Merzbacher, a materials scientist now immersed in quantum markets and based at SRI in Washington, D.C., gets to enjoy a front-row seat in the early days of this new era. Part of the excitement is about the expectations for new product development to fill key gaps.

"Many aspects of quantum information technologies are still in the R&D stage," Merzbacher says. "Components are not standardized or validated for the applications."

Her mission is easily stated, says Merzbacher: "We are growing the quantum industry." And it will take collaboration among many stakeholders.

Celia Merzbacher, of SRI International, runs the Quantum Economic Development Consortium, or QED-C. Credit: SRI International / Businesswire.

Her consortium seeks to promote the best work of new smaller companies developing the support technologies. "We are not picking winners," she says. "We enable them."

That is part of how her high-tech ecosystem is creating things on the very early days on this frontier. "It's very exciting," Merzbacher says.

Getting superconducting quantum computers to the marketplace will call for imaginative approaches. "It's still an emerging industry," she says.

QED-C is building upon substantial investments in basic research by government agencies, such as the National Science Foundation, the Department of Energy, NIST and the Department of Defense.

"We are assessing different quantum-based applications to identify needs for optics and lasers," Merzbacher said. "We are trying to enable the ultimate use cases by encouraging development of a robust supply chain."

The QED-C is well positioned to encourage quantum solutions to fill needs for many specialized control components needed for superconducting quantum computers.

Since many quantum systems are about interactions of light, one challenge is how to get light in and out, in a controlled environment, with just the right temperature and a vacuum.

"Integrated photonics will be essential, creating specialized packaging and controlled extreme environments with the ability for input and output of light and other signals," Merzbacher said.

Much of the work still happens in-house at various companies, she said.

"There are some potential apps in the nearer term, in areas related to sensor technology," she said. "Today, the research sector is itself a significant market, but there's a lot of growth, as research leads to development, deployment and use. They are creating stepping stones to the ultimate goal of commercial technology."

Some early products moving through the quantum pipeline are in areas of sensing capabilities, for example involving gravimetry. And a few of those breakthrough products are commercially available today.

To illustrate these breakthroughs, experts often cite one company that has worked with NASA on gravimetry challenges — the creative team at AOSense, an employee-owned company based in Sunnyvale, California.

Merzbacher says it shows how smaller companies are creating first generation technology.

"It's a prime example of a company that is creating innovative products with novel capabilities," she said.

"Their products are very specialized," she said, noting that the firm creates technology used for measuring incredibly small variation in gravity fields.

Satellite gravimetry

Working with a NASA team at the Goddard Space Flight Center in Greenbelt, Maryland, AOSense has demonstrated a novel quantum sensor for satellite gravimetry. AOSense has developed quantum sensors and atomic clocks since 2004, developing advanced sensors for precision navigation and timing.

Other quantum pioneers have entered the early stages of developing

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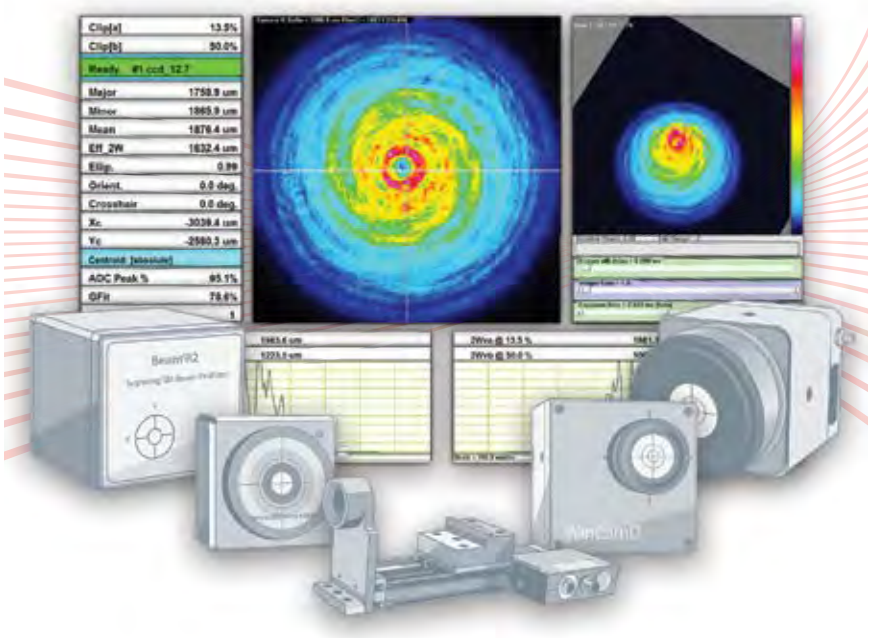

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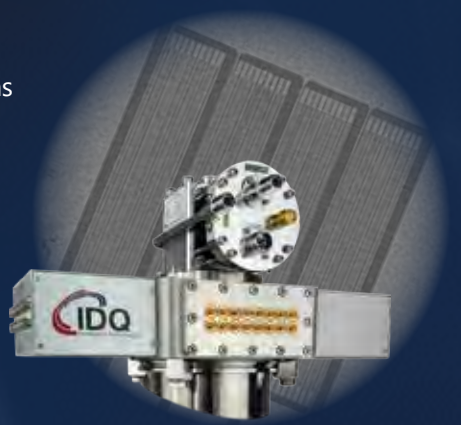

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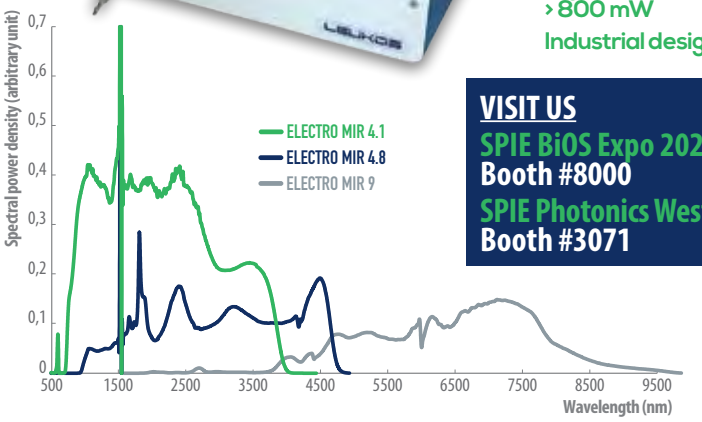

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Quantum photonics

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electromagnetic sensors for brain imaging. "If we didn't have to put the patient into an MRI machine, but could monitor them doing normal activity, we could get new and useful information about what's going on in their brain," Merzbacher said. "That technology is still down the road but it will provide us with important new capabilities. There's a lot of potential along those lines."

Much of the research in quantum photonics — taking advantage of quantum properties of light and matter interactions — is going to scale up in the near future, she predicted.

Much of the research in quantum photonics — taking advantage of quantum properties of light and matter interactions — is going to scale up in the near future.

With the expected growth in quantum photonics, workforce needs are also stepping up. Workforce training programs have appeared across the US, but questions remain on how to structure that training.

"There's a strong pull for people to come into this field. And yet, it's not immediately clear how to actually train the quantum workforce," said Dr. Prineha Narang, assistant professor of Computational Materials and Applied Science at Harvard University and Chief Technical Officer of Aliro Quantum. He was part of a University of Colorado study.

The good news is that the new jobs often will not require a PhD in physics, Merzbacher said.

QED-C has gathered data showing that many positions that companies will fill do not require many quantum-specific skills. Basic coursework in software engineering or in conventional skills like communications and business, along with a basic introductory course to understand quantum science may be enough to create an advantage in seeking a position.

Quantum physics, Merzbacher says, is ubiquitous and characteristic of nature at small scales.

"We just have to learn how to harness it." In turn, developing quantum computers poses unprecedented engineering challenges."

The industry side, said Lowell, will need components working at specific wavelengths that match the quantum systems that they are measuring. "If the photonics industry can meet those needs," Lowell said, "there are great partnerships to be had in the future."

FORD BURKHART

NASA's Goddard-AOSense team built this terrestrial proof-of-concept gravity gradiometer. Credit: NASA.

All systems go for free space optics

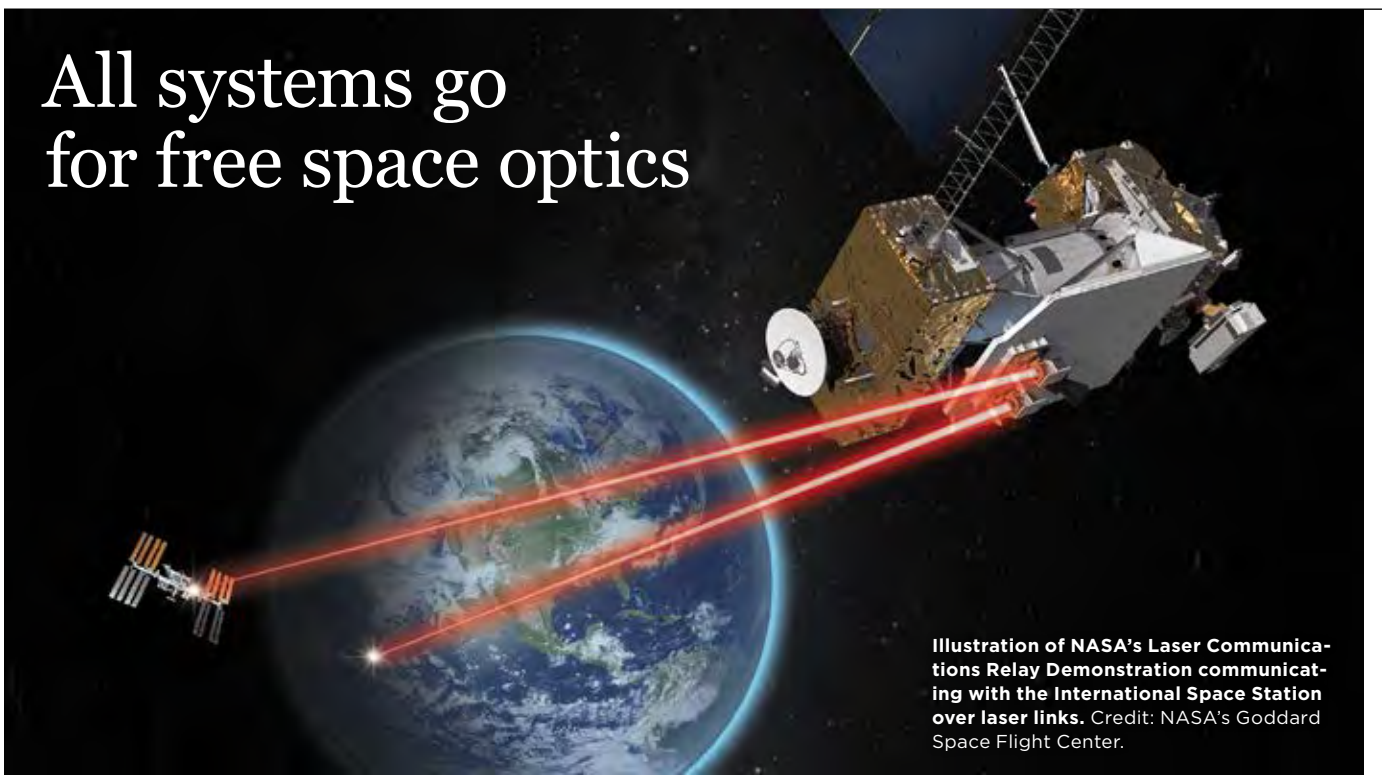


Illustration of NASA's Laser Communications Relay Demonstration communicating with the International Space Station over laser links. Credit: NASA's Goddard Space Flight Center.

With the laser communications market poised to explode, more and more free space optics firms are taking to the skies to deliver lightning-fast datacoms.

Without a doubt, the free space optics community has its work cut out right now. As the demand for data continues to rise and radio wavebands become congested, laser communications offer the potential to open up a far less busy portion of the electromagnetic spectrum, bridge the digital divide, and deliver blisteringly fast data transmissions.

But a quick glance at the Photonics West Free-Space Laser Communications XXXIV reveals that myriad challenges still persist. From honing laser beam pointing accuracy and reducing laser system power consumption to ensuring uplink laser safety and efficient constellation connections, researchers and engineers worldwide are racing to deliver results. And this isn't surprising given recent analysis from Global Market Insights predicts the FSO market will mushroom by an order of magnitude from some $200 million to $2 billion by 2027.

Jean François Morizur, CEO of Cailabs. Credit: Cailabs.

"For the first time since the 1960s, when the first tests were done on laser communications, there is a very real application in front of engineers working in the field," highlights Dr Hamid Hemmati, Vice President and Chief Technology Officer of the US satellite broadband player, ViaSat, which uses geostationary satellites to provide Internet access. "In the past, the market has only required a handful of optical transceivers every year but given the growing constellations of satellites in low Earth-orbit, this is now scaling to thousands per year."

According to Hemmati, who is opening the Photonics West Free-Space Laser Communication session with Dr Bryan S Robinson, MIT Lincoln Lab, companies already providing optical transceivers for flight include SA Photonics, US, and Germany's Tesat Spacecom and Mynaric. Meanwhile businesses such as SpaceX and Amazon are also developing optical transceivers in-house. Still, as Hemmati points out volume manufacturing is an issue for everyone and component costs need to drop substantially.

"Companies are getting squeezed in terms of cost of flight transceiver, manufacturing times and delivering higher data rates than ever before," he says. "Solutions include designing modular systems that can be put together without a lot of expertise and adding as much automation as possible — which isn't simple given the tight tolerances of optics."

"But I think companies welcome the challenge and the market potential is encouraging many to be innovative," he adds.

'A solution beyond radio'

Jean-François Morizur, Founder and CEO of France-based photonics components and systems developer, Cailabs, concurs. As he highlights: "Right now, the game is to provide a solution beyond radio… The market for free-space optical communication has a door opening because we are reaching a point where radio cannot move forward for fundamental reasons, including available bandwidth."

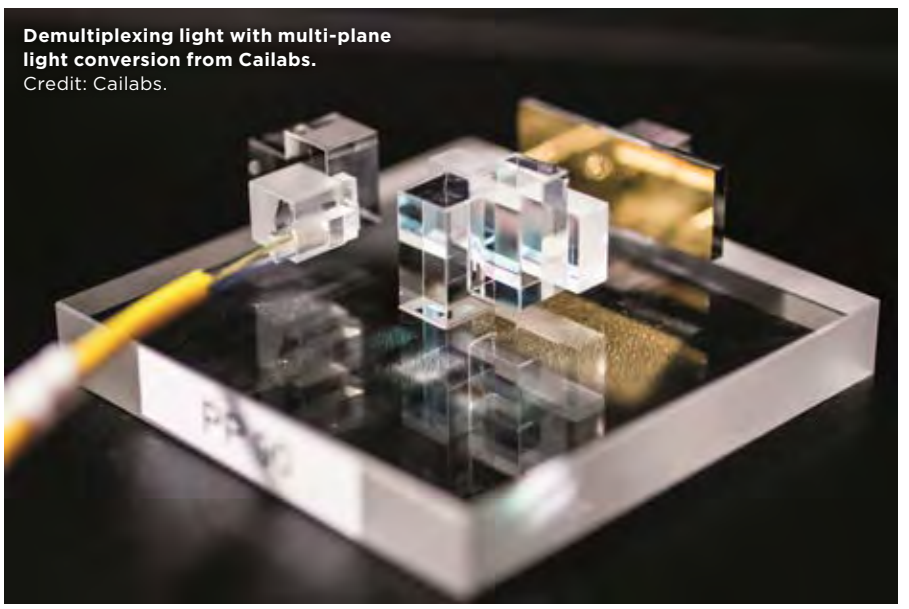
"So I see this friction and I think as the optical community we have to recognise this and say we can take you beyond radio with optics," he adds.

A key challenge for the FSO community is atmosphere turbulence. Fog, rain and other air movements scatter the laser light as it travels from a low Earth-orbiting satellite to ground-stations, degrading the signal and reducing the reliability of long-range links. To counteract this, highly sensitive FSO receivers have been used to process incoming multimode light, but given the large footprint of many such systems, Cailabs pioneered a compact, spatial mode demultiplexer based on Multi-Plane Light Conversion (MPLC). And this is now making in-roads to the latest FSO communications receivers.

The technology comprises a series of phase plates and lenses that shape the multimode light from a satellite into different single modes, ready for recombining into a single-mode fiber. Early results indicated that using a MPLC-based spatial mode demultiplexer increases signal collection at the FSO communications receiver, even following strong atmosphere turbulence. As Morizur highlights: "We presented a paper on using a MPLC spatial mode demultiplexer for turbulence mitigation at Photonics West 2019 and our story has basically accelerated from here."

Indeed, Cailabs is now playing a key role in the €5.5 million ($6.2 million) Keraunos project, funded by the French Defense Innovation Agency to tackle atmosphere turbulence during FSO communications. Here, a nanosatellite, designed and launched into low earth orbit by France-based satellite start-up, Unseenlabs, will transmit a signal to a ground-based station with a FSO receiver that contains Cailabs' spatial mode demultiplexer. Tests have started and Morizur reckons the nanosatellite could launch later in 2022. "Atmopspheric mitigation is a challenge and ambitious, but the Keraunos project will accelerate development here," he says.

In the meantime, Morizur's colleague, Guillaume Labroille is also presenting recent Cailabs research at Photonics West, in which its spatial mode demultiplexer has been combined with a lithium niobate photonic integrated circuit (PIC) to process incoming atmosphere-disturbed signals. "I also see a lot of people excited about using PICs because these simplify the design of any system that deals with turbulence," highlights Morizur.



Demultiplexing light with multi-plane light conversion from Cailabs. Credit: Cailabs.

Indeed, just south of Paris, France, Dr Vincent Billault and colleagues from Thales Research & Technology and Thales

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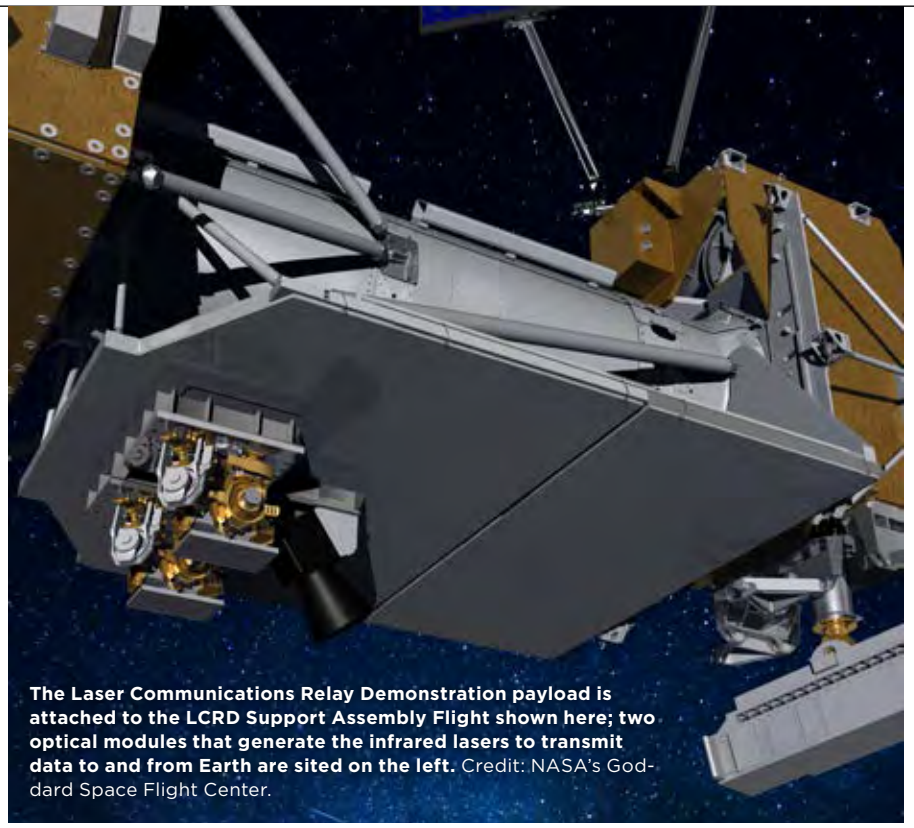

The Laser Communications Relay Demonstration payload is attached to the LCRD Support Assembly Flight shown here; two optical modules that generate the infrared lasers to transmit data to and from Earth are sited on the left. Credit: NASA's Goddard Space Flight Center.

Free space optics

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Alenia Space, Toulouse, have developed a prototype FSO receiver that includes a Cailabs MPLC module and their custom-designed photonic integrated circuit. Here, the demultiplexed light is shunted into the PIC where it is re-combined to single-mode light, on chip, ready for high-speed transmission.

Billault will present results at Photonics West and believes he and colleagues are amongst the first to use PICs — adaptive optics are an alternative option that have found success in many FSO receiver set-ups. "We developed a photonic integrated circuit as you can pack a lot of optical and electrical functions onto the chip and that's very interesting for the scalability, the footprint and the thermal and mechanical stability of the multi-mode laser light combiner," he says.

The Thales-designed PIC was fabricated within the silicon on insulator photonics foundry at Belgium-based nanoelectronics research center, imec, and packaged by integrated photonics packaging foundry, Phix, of The Netherlands. It comprises numerous phase shifters, Mach-Zehnder interferometers and photodiodes in a small footprint, which according to Billault, combined with the spatial demultiplexer, delivers a robust and adaptable system package. Indeed, Thales Alenia Space is keen to develop the product further.

PICs for satellite laser communications from LEO Space Photonics. Credit: LEO Space Photonics.

To test their receiver, the researchers designed an atmospheric perturbation emulator to mimic an entire optical link from satellite to receiver. So far, results indicate their set-up is strongly resilient to phase and amplitude perturbations compared to conventional single-mode fiber FSO receivers. As Billault highlights: "I believe the whole mindset of the FSO sector is now shifting towards optical solutions."

"It's going to take some time to have these optical elements specified for space... but we're excited about our latest results because they prove that photonic integrated circuits can be implemented in space solutions," he adds. "PICs provide low weight, low power consumption and high flexibility, and this will be key for the future development of satellite applications."

Greece-based start-up, LEO Space Photonics, is also making waves in the world of satellite optical communications. From word go, CEO and company founder, Dr Leontios Stampoulidis, and colleagues, have focused on making electronic and photonic transceiver ICs for laser communications (lasercom) between satellites, and have been instrumental to key, multi-million dollar European Horizon 2020 projects. One such project, ORIONAS, has developed optical transceivers and amplifiers for lasercom modems with a view to delivering >50 Gb/s direct and coherent detection links to the world's growing army of satellite constellations.

As the project draws to an end, Stampoulidis is presenting results at Photonics West, which as he highlights, will be critical to reducing the cost, complexity and size of lasercom terminals for high-speed satellite constellation interconnectivity. Researchers have been working with BiCMOS and InP foundries to squeeze transceiver and amplifier elements into ICs of only a few square millimeters while co-packaging modulator PICs with laser diodes and developing radiation-resistant fiber pre-amplifiers.

The next steps are to ensure all fabrication processes are repeatable and reliable as device testing takes place at Thales Alenia Space.

"This is all about progressing the sustained entry of photonics integration in satellites, which is so important," says Stampoulidis. "Today we have only two mission-critical mini constellations in the sky that use lasercom — the European and Japanese data relay systems — but tomorrow is going to be very different... in the last decade around 500 telecom satellites were launched in total but almost overnight, SpaceX launched 60 in one day, and projections indicate that the industry will launch 30,000 satellites from 2020 to 2030."

"If we're talking about tens of thousands of satellites then cost is an issue — we need to make systems much more compact, densely integrated and cost-effective, and photonics integration is going to play a role," he adds.

NASA testing FSO in space

Clearly industry progress is rapid. For example, NASA's Laser Communication Relay Demonstration, aboard the U.S. Department of Defense's Space Test Program Satellite-6, will test laser communications from geosynchronous orbit to Earth. And in addition to the proposed nanosatellite to Earth link from the French Keraunos project, Stampoulidis points to similar endeavors, including a Photonics West presentation from Kathleen Riesing at MIT Lincoln Lab on the Terabyte Infrared Delivery program. Here, MIT researchers are working with NASA, Ames Research Center and the Goddard Space Flight Center, to deliver record-fast, 200 Gbps data rates from a low-Earth orbit small satellite to a ground station.

"They're actually installing a photonic integrated circuit transceiver onto a CubeSat and will fly this to show it can survive in space," says Stampoulidis. "These systems are getting so small they can now fit into a CubeSat."

Critically, demonstrations such as this, as well as low Earth-orbit satellite launches from the likes of SpaceX, OneWeb and Amazon, are stimulating more and more private investment at a time when homogenized terrestrial telecoms standards are also fuelling space-based development. And this spells good news for the likes of LEO Photonics Space, Cailabs and other start-ups.

"Space is becoming more accessible and embracing innovation," asserts Stampoulidis. "And a lack of big players here means we don't have to make systems in a specific way, and industry is open to disruptive solutions."

Still, the LEO Space Photonics CEO also provides a few words of caution: "If the technology reaches the mega-constellations then this market will be huge, but we cannot assume that all future satellites will carry laser communications," he says. "We now need to watch what happens with, for example, Telesat's satellites and the Starlink constellation, and look for viability from both a technology and business point."

In the meantime, ViaSat's Hemmati also urges more universities to educate laser communication engineers. "This really is an exciting time [for free space optics] but there are not enough experts trained in laser communication," he says. "I've taught some classes, but such an education is not generally available, so my recommendation would be for universities to start teaching free space laser communication now."

REBECCA POOL

The Thales PIC, as packaged by Phix. Credit: Phix.

Quantum dots shape the future of photonic integrated circuits

It was standing room only at John E. Bowers' talk, "Laser Integration on Silicon for Photonic Integrated Circuits," on Monday at Photonics West. At University of California, Santa Barbara, he is the Fred Kavli Chair in Nanotechnology, director of the Institute for Energy Efficiency, and a distinguished professor in the Departments of Electrical and Computer Engineering and Materials.

Bowers noted that there are two approaches to laser integration on silicon, both with their share of advantages and roadblocks for commercialization. He also posited they share in their ability to take advantage of quantum dot technology.

Heterogeneous integration of lasers using Si waveguides, by companies like Intel and Juniper, is an elegant path for the inclusion of a laser source—either quantum well or quantum dot—on a silicon (Si) photonics platform. It is available today and allows flexible addition of different functionalities.

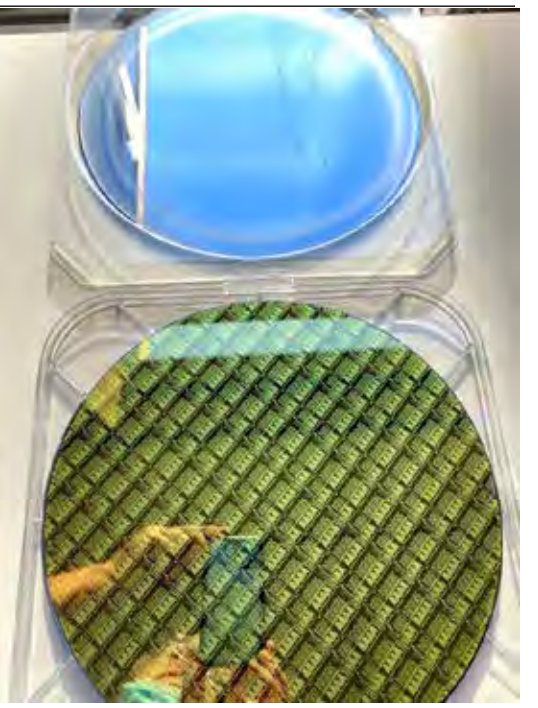
Monolithic integration on Si under development by AIM and Quintessent, would use quantum dots grown epitaxially on silicon. This will offer the best economies of scale, he said, and eliminates bonding and the need for III-V substrates. Challenges of epitaxial integration include crystal lattice mismatch and thermal expansion mismatch.

Economics and the growing bottleneck for moving data across electronic circuits will drive progress in PIC development, he said. He projects that switch bandwidth will need to double every two years, moving from 25.6 Tb/s today to up to 204 Tb/s in five-years' time with 3D co-packaging as the route.

Complex, high-performance photonic integrated circuits are being commercialized on silicon substrates by Intel, Cisco, Acacia, Juniper Networks and more in high volume: more than 3 million in 2021. Juniper has achieved the highest level of laser integration on silicon with more than 1,500 elements on chip. He notes rapid progress in epitaxial lasers on silicon, achieving a 200,000-hour operating lifetime at 80 degrees C. The integration of lasers, modulators, and photodetectors on silicon is in high-volume production, exceeding 1 million transceivers per year; the low-noise performance on silicon is excellent.

Why use quantum dots, Bowers asked. Because they are insensitive to defects and sidewalls, they record CW operating temperatures of 220 degrees C, their low threshold current, they are insensitive to reflections, and there is reduced lateral diffusion along with low noise mode locking.

WILLIAM SCHULZ



The top wafer show monolithic laser integration using quantum dots. At bottom, an Intel wafer employing heterogeous laser integration. Courtesy: John Bowers.

Laser-lit

continued from page 01

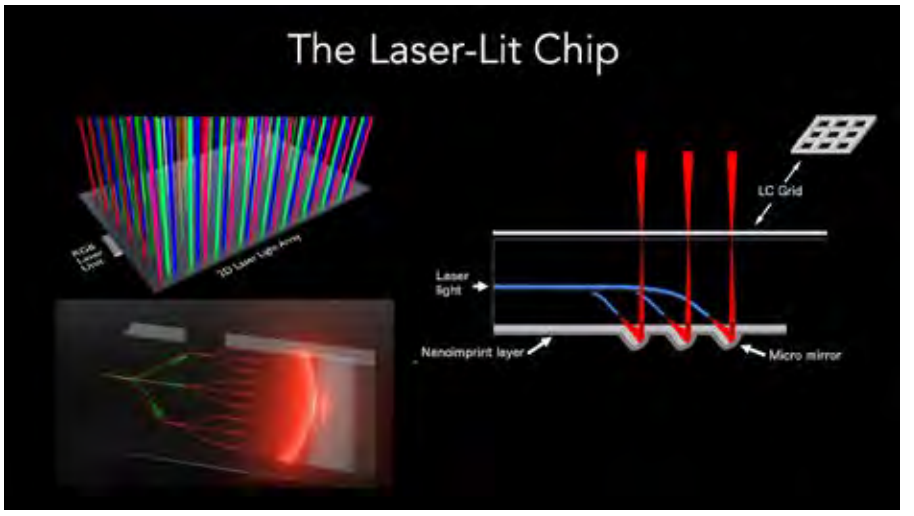
on the startup's innovative technology to bring laser light to displays. Using a combination of laser diodes, custom-built waveguides, and nanoimprint technology, Zeuner believes VitreaLab (Booth 3020) is primed to deliver on their promise of brighter and more efficient displays via their photonic integrated circuits in the coming years.

VitreaLab's technology would replace the standard backlight unit of an LCD, supplying each sub-pixel with a dedicated light source with the correct color, polarization, and angular distribution. This approach, said Zeuner, improves the LCD's energy efficiency, brightness, contrast ration, and color rendering.

Using direct laser writing with femtosecond pulses, they can create 3D waveguides directly on the glass. "A piece of glass is modified with direct laser writing, and we're able to generate a dense grid of parallel laser beams in red, green and blue coming out of this glass surface," said Zuener.

"It's going to be millions of beams. And in fact, we can space these beams so densely that you can use this thing slotted behind an LCD and you have one laser beam per pixel in your display. It's completely changing the optical dynamics and light control capabilities of your screen."

Currently in the lab, the company is able to get roughly three times improvement in energy efficiency over current LCD technology. But with further improvements of the technology, they think a 10x factor or even more is possible while remaining cost competitive to other display technologies. They state this is mostly because they replace just one component of the overall display stack and are not recreating a complete new display technology, which will also make the technology compatible with many other applications in the display field.



(Above) Award-winning technology. Courtesy: VitreaLab.

(Right) That winning feeling: Jonas Zuener pitches VitreaLab. Credit: Joey Cobbs.

Zuener continues, "Towards the end of the year, we're going to build another set up and then work on towards the generation two process. This is going to be already using the multi-beam writing. Our target is an iPhone one type display in terms of size and resolution."

The company is aiming to reach mass production in about five years' time, said Zuener. "For those that know laser writing in depth and always have been wondering if you can do mass manufacturing with such a direct riding approach, well, luckily, you can. And this is mostly because now femtosecond lasers produce a lot of power for fairly little money."

On winning the challenge, Zuener said, "I think it was an absolutely fantastic result to be at this biggest photonics event and at this Startup Challenge because it means a lot of outreach possibilities, a lot of people will see us, and we can get in touch with investors so fast. It's a very, very useful result. We are very appreciative."

KEVIN PROBASCO

Edmund Optics debuts its Schwarz Mirrors to curb stray laser beams

In laser applications, unwanted transmission can require a "beam dump" to be positioned behind every mirror to prevent unwanted light propagation. Novel mirrors called Schwarz Mirrors (patent pending) based on an engineered substrate — developed by Edmund Optics (Booth 627) — can reduce the power leaking through a component by several orders of magnitude while maintaining >98 percent of the reflective properties.

The Schwarz Mirrors will launch with a 25.4mm diameter x 6.35mm thick sample, with a VIS coating (350-700nm). The substrate itself is an engineered fused silica that is black in appearance; it has identical properties to traditional fused silica (including its characteristic lower thermal expansion and high durability) with the added benefit of having OD7 blocking in the visible range.

Ian Schwartz, a product line engineer at Edmund Optics, explained, "The primary applications are laser safety, stray light control, and reduction of optical system size per cost. We expect these to be very popular in the defense industry as well as laser manufacturing and autonomous vehicles."

Rated as both mirrors and neutral density filters, these parts greatly reduce the need for beam dumps behind components, minimizing the size of optical systems and improving laser safety. The products are making their debut this week and a soon-to-be published paper will discuss the performance of these engineered mirrors and compare their reflection and transmission with traditional fused silica mirrors.

Ian Schwartz, Product Line Engineer says the mirrors will be "very popular in the defense sector." Credit: Joey Cobbs

Likely markets for the Schwarz Mirrors will be in laser development, augmented and virtual reality display systems, and the wider OEM manufacturing sector.

MATTHEW PEACH

One potato, two potato, Tri potato: (from left) new Trioptics CEO Kristin Holzhey, CSO Simon Zilian, CTO Stefan Krey, CFO Joern Luethje, and company founder Eugen Dumitrescu. Photo: Trioptics/Jenoptik.

NEW TEAM AT TRIOPTICS AS FOUNDER DUMITRESCU STEPS DOWN

Optical metrology specialist Trioptics has appointed a new CEO to take over from company founder Eugen Dumitrescu, who is stepping down from his executive position after 30 years at the helm of the Wedel, Germany, company.

Dumitrescu will hand over responsibility to new CEO Kristin Holzhey, while Simon Zilian is promoted to lead the Trioptics sales effort. They join Stefan Krey and Joern Luethje, who had already been appointed to the positions of CTO and CFO, respectively.

Holzhey has been with Jenoptik — which acquired Trioptics in September 2019 - since 2007. During that time she has held various positions within the firm, including a period as an advisor to the CEO, and more recently as the managing director of OTTO Vision Technology. Holzhey has also taken charge of the integration of Trioptics within Jenoptik since 2020.

Dumitrescu, who founded the company back in 1991, will remain as an active managing director until the end of March, and will subsequently become a member of Jenoptik's advisory board.

MIKE HATCHER

Luminar continued from page 01

and development phase into series production programs with top automakers. Partners like Volvo and Mercedes-Benz see the opportunity for lidar to make their cars substantially safer while paving the way for autonomous capabilities," Eichenholz said.

After a few years of running in stealth mode, it was actually at Photonics West a few years ago where Eichenholz and Luminar first let the photonics industry know about Luminar. Since then they have passed several milestones, detailed by Eichenholz.

"It has been a whirlwind! Arguably the biggest achievement, and every entrepreneur's dream, was our public listing just over a year ago in December. That gave us the capital we needed to accelerate our trajectory. Since that time, we have won major commercial deals like Mercedes-Benz, acquired OptoGration a critical component provider, advanced both our lidar and associated software and almost doubled our number of employees."

Jason Eichenholz. Courtesy: Luminar Technologies

As the public announcements and accompanying press keep coming, the team in Orlando is busy making sure the technology matches the needs of its partners, as he explains.

"We are hard at work industrializing and scaling our product and processes to serve the series production program wins we have. We are now in the critical industrialization phase of our first, series production sensor called Iris. We plan to start Iris production at the end of this year.

"At the same time, my team is focused on the necessary R&D and investments to ensure we have leadership technology on our roadmap from the chip-level, up for the years to come," he adds.

While the current partnerships show the industry's growing acceptance of Luminar's technology, it's clear that while they are helping remove driver's feet from the pedals, their own feet remain fully pressed on the gas.

"I walk the floor and attend technical sessions at SPIE Photonics West to see how technology is progressing and meet the inventors behind the breakthroughs. My job is to ensure Luminar's technology roadmap stays at the forefront. I wouldn't miss this show!

"When it comes to next-generation safety and autonomy in transportation, we are really just getting started. Huge advancements in photonics are necessary to realize a world where humans aren't killed or injured in traffic accidents."

KEVIN PROBASCO

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